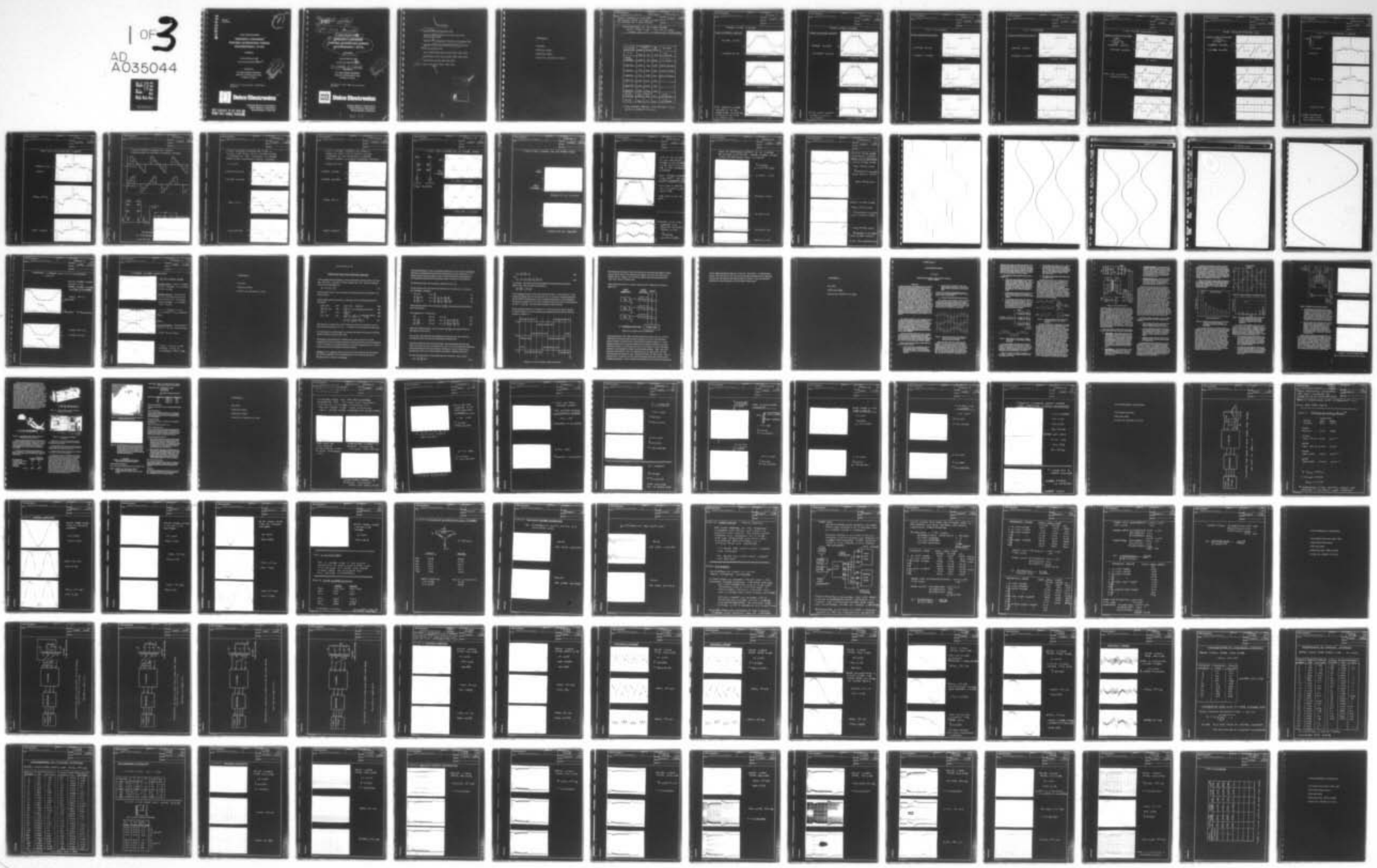
AD-A035 044    GENERAL MOTORS CORP  GOLETA CALIF DELCO ELECTRONICS DIV    F/G 9/5
FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
MAY 74  T CORRY, BARRETT    DAAK02-72-C-0210
UNCLASSIFIED    R74-40-VOL-2    NL

1 OF 3
AD
A035044



B.S.

ADA035044

R74-40
MAY 1974

1

FINAL TECHNICAL REPORT

# FREQUENCY CONVERTER
# PORTABLE, ALTERNATING CURRENT
# MULTIFREQUENCY, 10 KW

## VOLUME II

Contract CDRL Item A002

Contract No. DAAK 02-72-C-0210

Submitted to

U.S. ARMY MOBILITY EQUIPMENT
Research and Development Center
Fort Belvoir, Virginia



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Delco Electronics

General Motors Corporation
- Santa Barbara Operations
Santa Barbara, California

(14) R74-40-Vol-2
(11) MAY 1974
(12) 242p.

(10) T. Corry / Barrett

(9) FINAL TECHNICAL REPORT,

(6)
# FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENCY, 10 KW.

## VOLUME II.

Contract CDRL Item A002

Contract No. DAAK 02-72-C-0210

(15) DAAK02-72-C-0210

Submitted to

U.S. ARMY MOBILITY EQUIPMENT
Research and Development Center
Fort Belvoir, Virginia



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Delco Electronics

General Motors Corporation
- Santa Barbara Operations
Santa Barbara, California

406 400

CONTENTS:

## APPENDIX A

Item 0004

CDRL Item A0002

Modification P0006

Contract No. DAAK02-72-C-0210

| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO.<br>ITEM 0002 | PAGE | JOB NO.<br>APPENDIX A | PAGE<br>1 |
|---|---|---|---|---|
| TITLE<br>10KW FREQUENCY CONVERTER<br>ITEMS 0001, 0003 AND 0004 CONTRACT<br>NO. DAAK02-72-C-0210 REPORT | | PREPARED CORRY<br>CHECKED<br>APPROVED | | DATE 1/24/72 |

MEASUREMENTS OF THYRISTOR VOLTAGES
400 HZ, THREE PHASE, 11KW, PF=0.8 LOAD
(THREE WIRE INPUT, NO TRANSISTORS, 125 MFD. LT-N)

| THYRISTOR DESIGNATION | MAX. VOLTAGE (VOLTS) FORWARD | REVERSE | $\frac{dv}{dt}$ V/μsec. | REMARKS |
|---|---|---|---|---|
| T+, T- | 320 | 40 | 150 | WITH SUPPRESSORS |
| POWER CENTER | 350 | 90 | 200 | AT TOP OF WAVE |
| STEP #0 | 225 | 130 | 280 | 70V IN 1/4 μsec. |
| STEP #1 | 150 | 200 | 200 | 100V IN 1/2 μsec. |
| STEP #2 | 160 | 180 | 240 | 60V IN 1/4 μsec |
| STEP #3 | 140 | 210 | 100 | |
| STEP #4 | 120 | 240 | 150 | |
| $R_E$ & $L_S$ | 350 | 260 | 200 | |
| PHASE SELECTOR | 300<br>380 com. | 380 com.<br>300 | 100 | WITH SUPPRESSORS |
| $T_C^+$, $T_C^-$ | 325 | — | 200 | WITH SUPPRESSORS |

(INPUT VOLTAGE = 295 VDC; OUTPUT VOLTAGE = 117 Vrms; OUTPUT CURRENT = 38 A rms)

DISTRIBUTION:

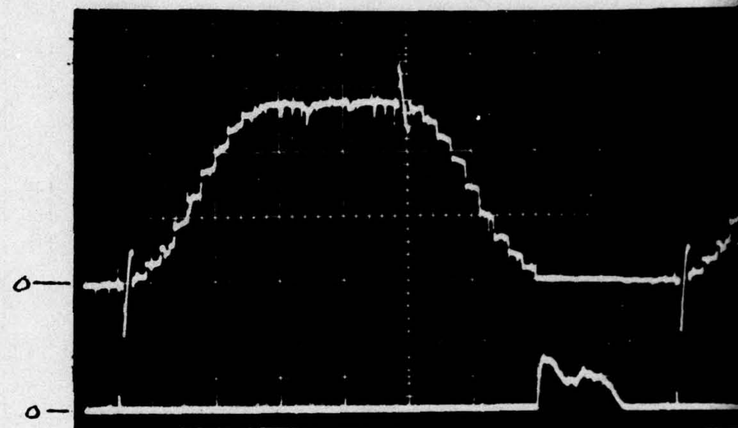
DF-255 REV. 12-66

POWER CENTER THYRISTORS

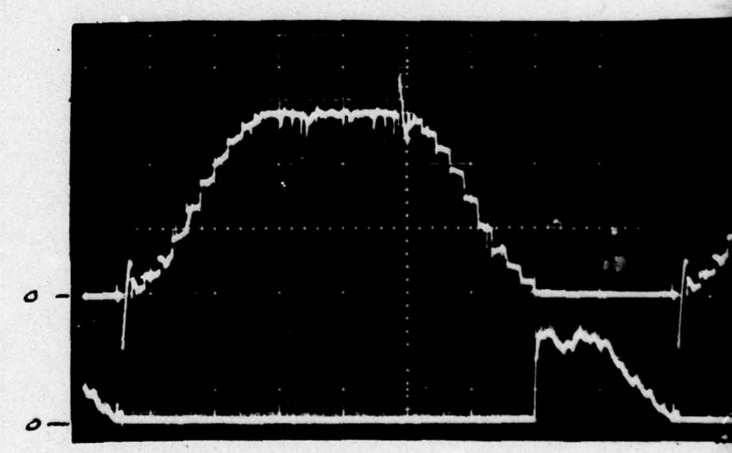
ANODE VOLTAGES & CURRENTS

VOLTAGE 100V/DIV

CURRENT 50A/DIV.

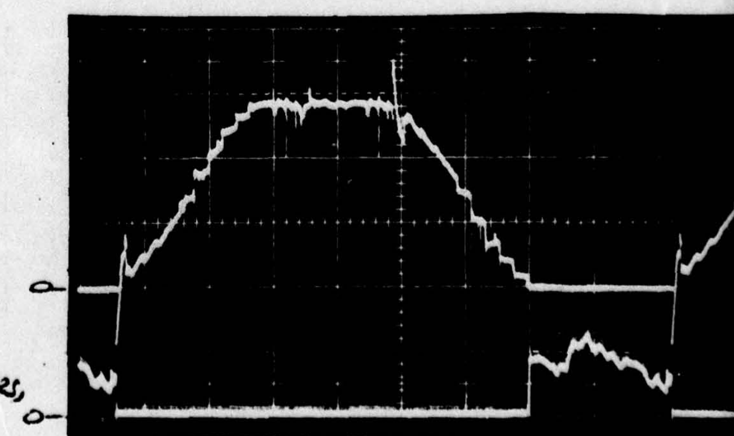



NO LOAD




11KW, PF=1.0

(NOTE: FREQUENCY CONVERTER OPERATING AT 400 HZ, THREE PHASE, NO TRANSISTORS, 125 MFD LT-N FOR PHOTOS ON PAGES 2-15)




11KW, PF=0.8

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| | CHECKED | |
| | APPROVED | |

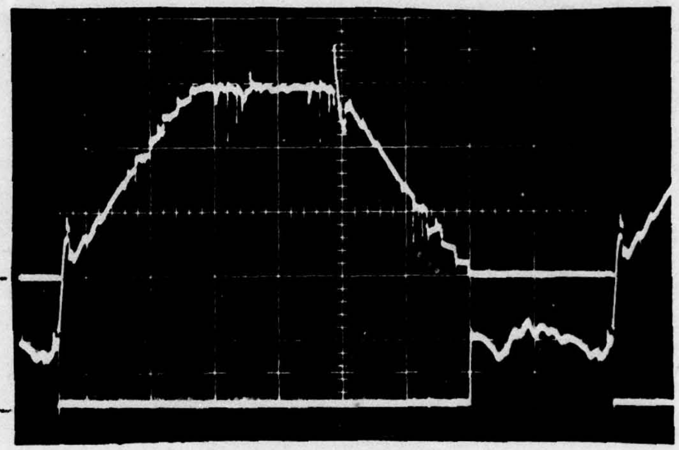
POWER CENTER THYRISTORS

ANODE VOLTAGES & CURRENTS

VOLTAGE 100V/DIV.

CURRENT 50A/DIV.

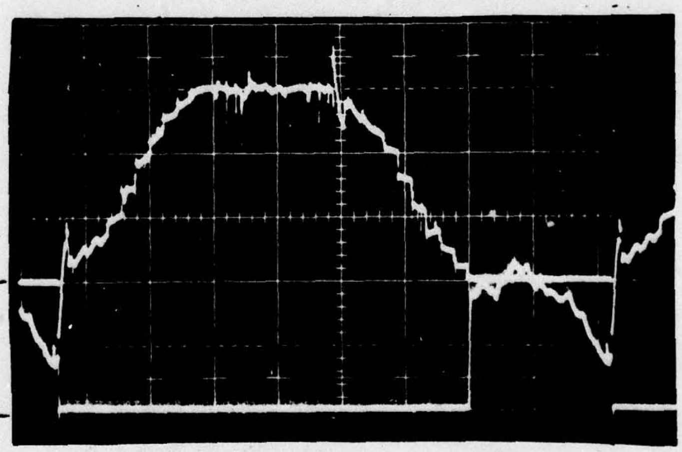
0—



0—

13.6 KW, PF= 0.8

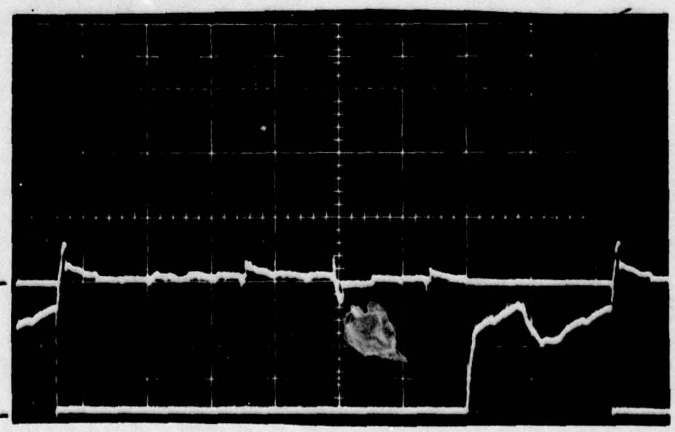
0—



0—

22KW, PF= 1.0

0—



0—

(SHORT CIRCUIT CURRENT LIMITED TO 60 A rms. $V_{DC}$=17.5VDC)

SHORT CIRCUIT

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DE 255 REV 12-66

| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO. | PAGE | JOB NO.<br>APPENDIX A | PAGE<br>4 |
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| | | CHECKED | | |
| | | APPROVED | | |

T+, T- THYRISTORS

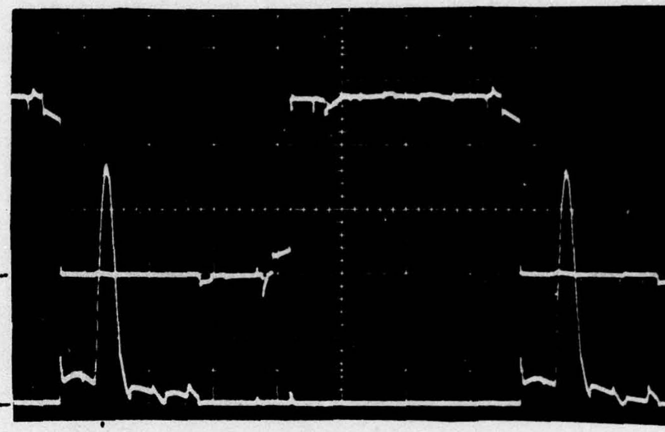
ANODE VOLTAGES & CURRENTS

VOLTAGE 100V/DIV.

CURRENT 50A/DIV.

0 —

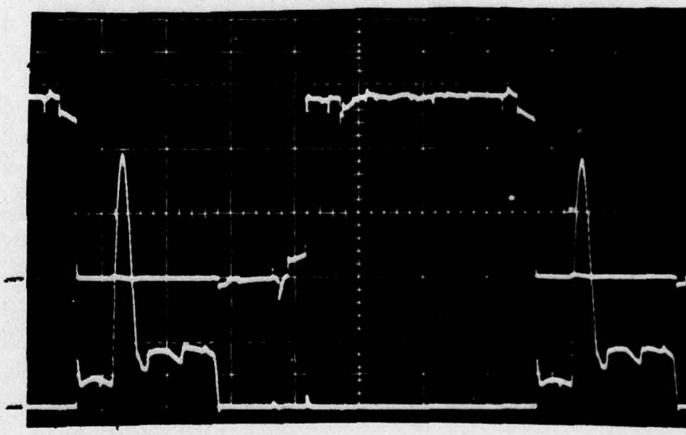
0 —



NO LOAD

0 —

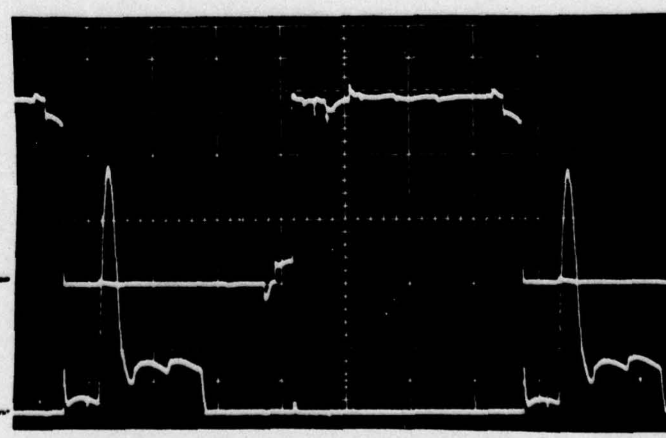
0 —



11KW, PF=1.0

0 —

0 —



11KW, PF=0.8

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| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO. | PAGE | JOB NO.<br>APPENDIX A | PAGE<br>5 |
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| | | | APPROVED | |

T+, T- THYRISTORS

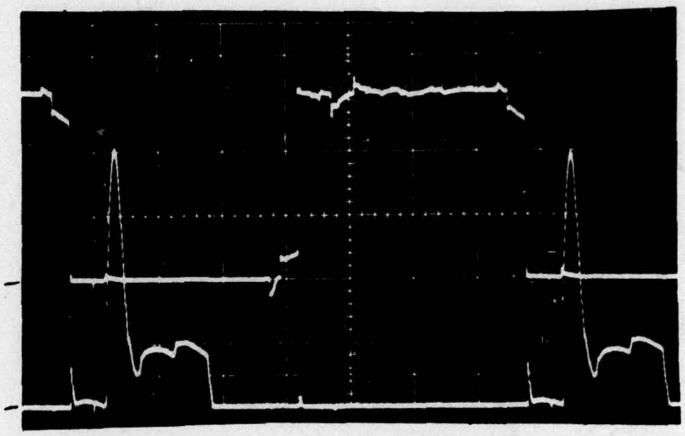
ANODE VOLTAGES & CURRENTS

VOLTAGE 100V/DIV.

CURRENT 50A/DIV.

0 -

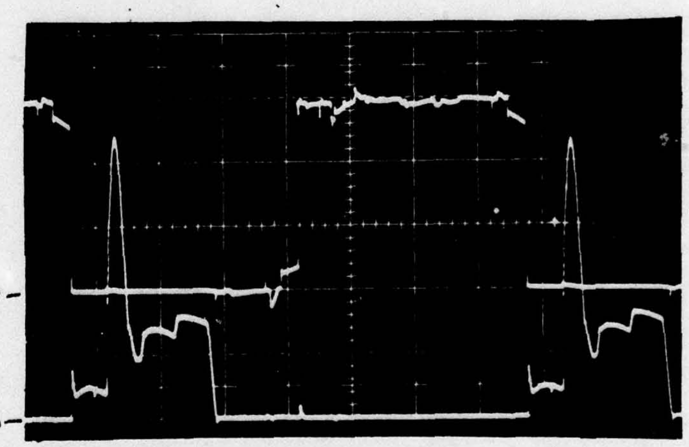
0 -



13.6KW PF=0.8

0 -

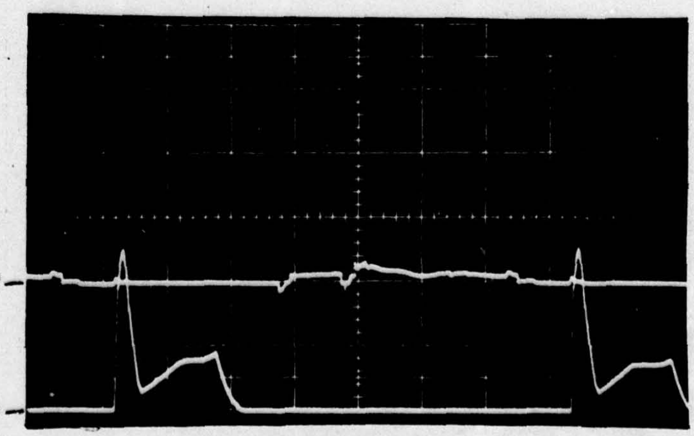
0 -



22KW, PF=1.0

0 -

0 -



SHORT CIRCUIT

DISTRIBUTION:

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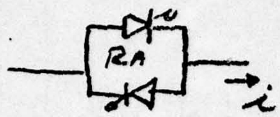
|---|---|---|---|---|
| TITLE | | PREPARED CORRY | | DATE 1/29/74 |
| | | CHECKED | | |
| | | APPROVED | | |

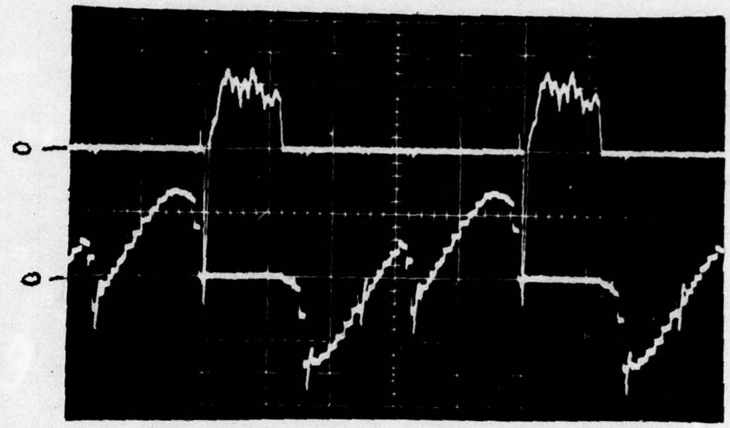
PHASE SELECTOR THYRISTORS (RA)

ANODE CURRENTS & VOLTAGES



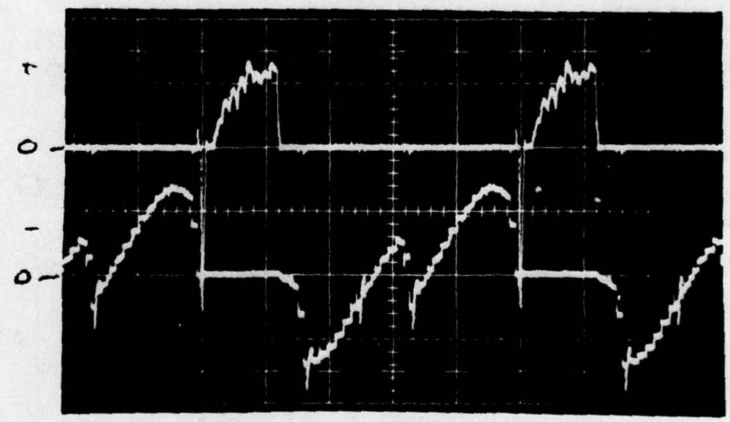

CURRENT 50A/DIV.

VOLTAGE 200V/DIV.

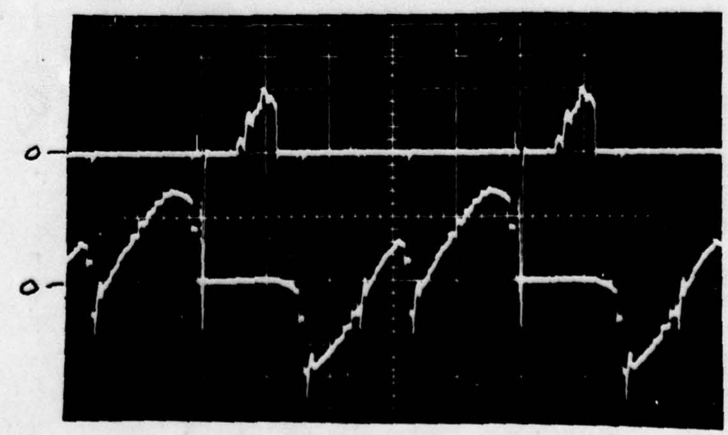



NO LOAD

(NOTE: NEG. COMMUTATION CURRENT 125 A. PEAK)




11 KW, PF = 1.0




11 KW, PF = 0.8

DISTRIBUTION:

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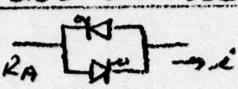
| | | | CHECKED | |
| | | | APPROVED | |

PHASE SELECTOR THYRISTORS ($R_A$)

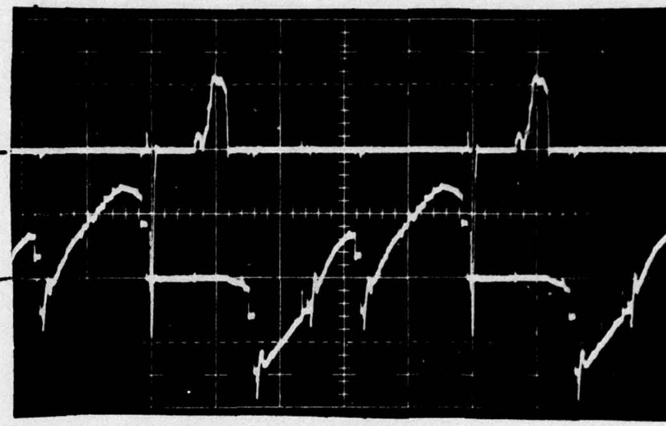
ANODE CURRENTS & VOLTAGES




CURRENT 50A/DIV.

VOLTAGE 200V/DIV.

0 –
0 –



13.6 KW PF = 0.8

0 –
0 –

22 KW, PF = 1.0

0 –
0 –

SHORT CIRCUIT

DISTRIBUTION:

DE 255 REV. 12/66

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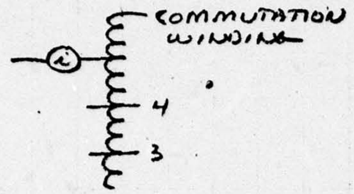
| | | APPROVED | | |

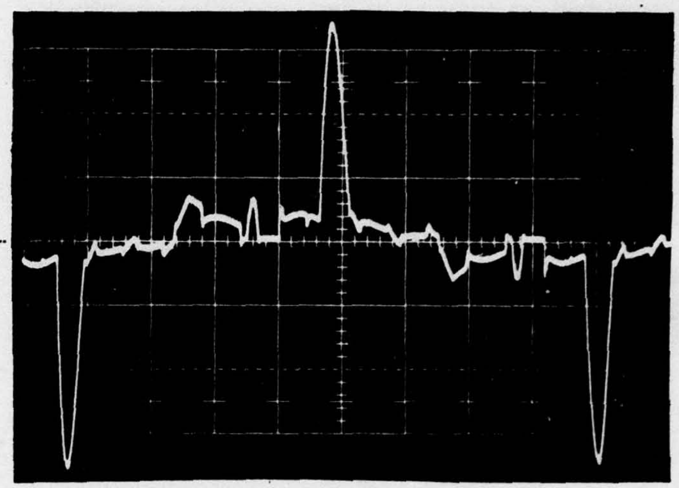
STEP AUTO-TRANSFORMER CURRENT




NO LOAD

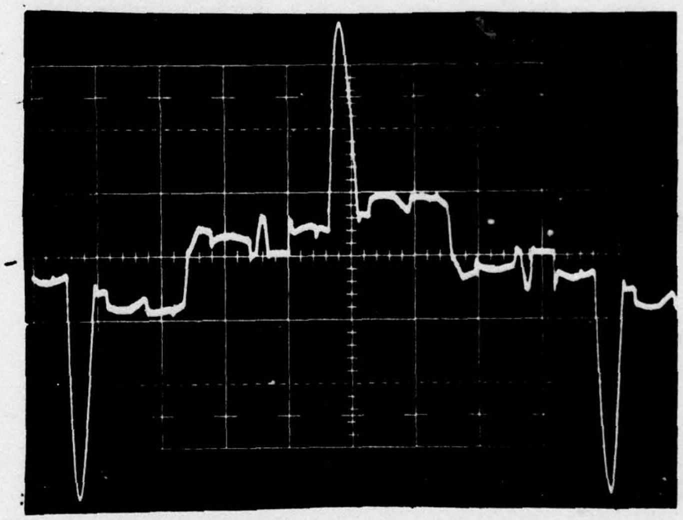
50A/DIV.

0-



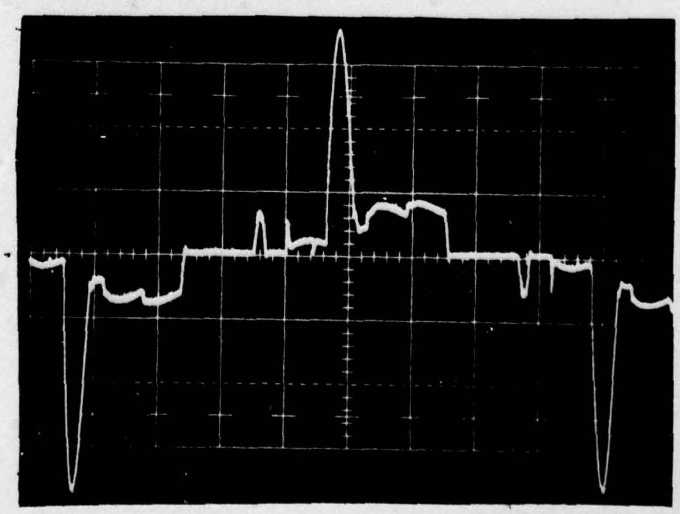
11KW, PF=1.0

0-



11KW, PF=0.8

0-



(NOTE: COMMUTATION PULSE GOES THRU TOP WINDING ONLY)

DISTRIBUTION:

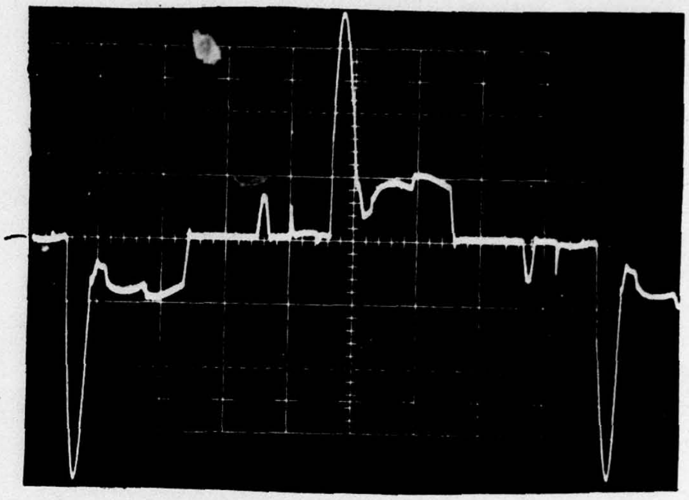
| TITLE | PREPARED CORRY   DATE 1/29/79 |
|---|---|
| | CHECKED |
| | APPROVED |

STEP AUTO-TRANSFORMER CURRENT

13.6KW, PF=0.8

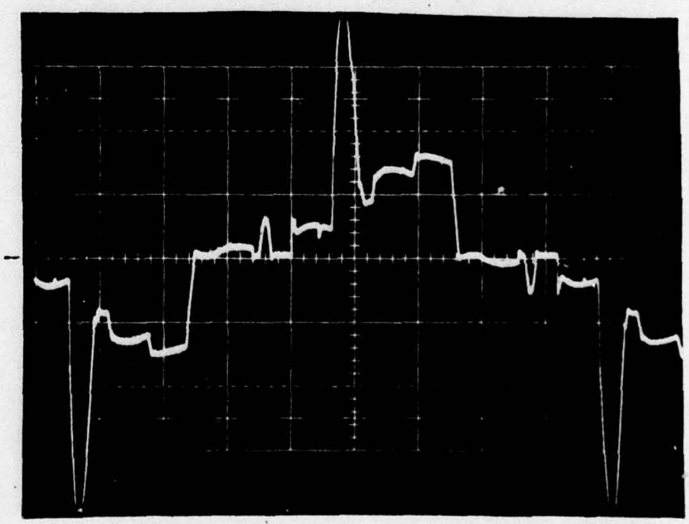
50A/DIV.

0 -



22KW, PF=1.0

0 -



SHORT CIRCUIT

0 -

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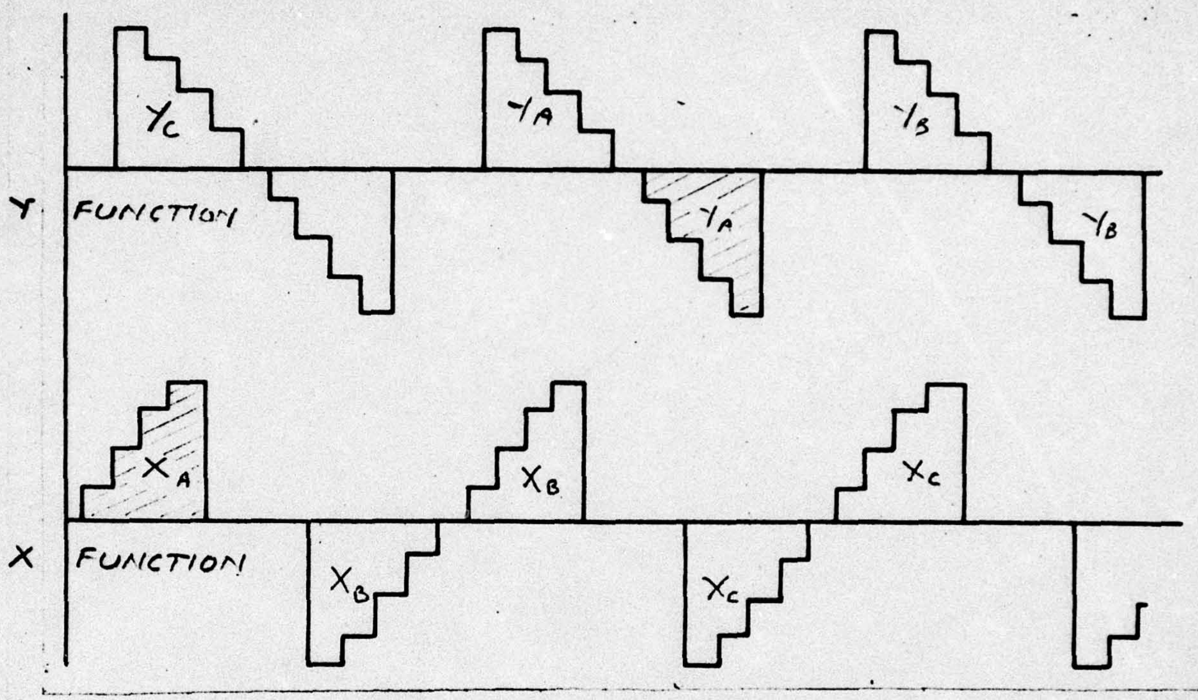
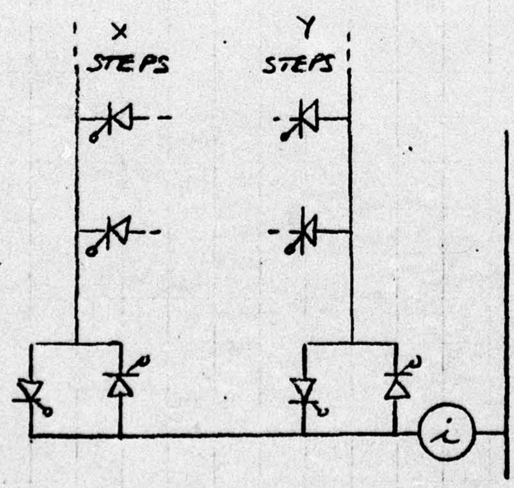
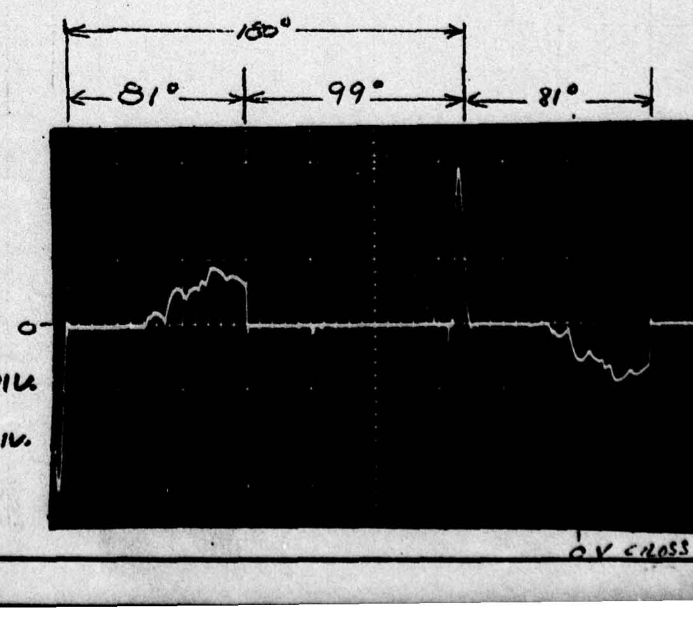
| | | APPROVED | | |

X AND Y FUNCTION CURRENTS FOR PHASE A.
(POWER CENTER COMMUTATION CURRENTS INCLUDED)




↕ 50A/DIV.

↔ 200 μ SEC/DIV.

11KW, PF = 0.8

DISTRIBUTION:

X AND Y FUNCTION CURRENTS FOR PHASE A SHOWN WITH BASIC LINE-TO-NEUTRAL VOLTAGE WAVEFORM OF THE FREQUENCY CONVERTER. (POWER CENTER COMMUTATION CURRENTS INCLUDED)

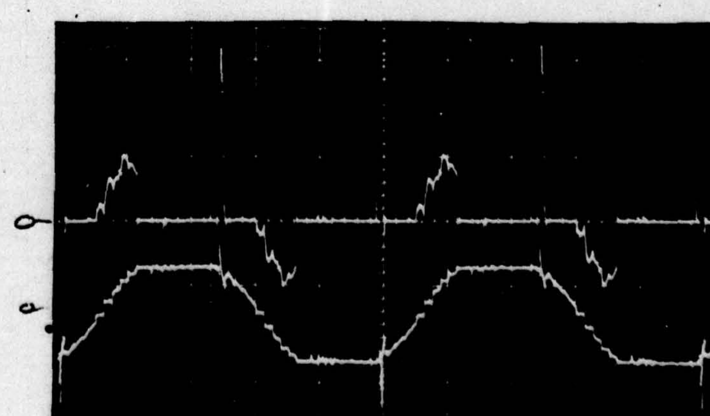
NO LOAD

CURRENT 50A/DIV.

VOLTAGE 200V/DIV.

11KW, PF=1.0

11KW, PF=0.8



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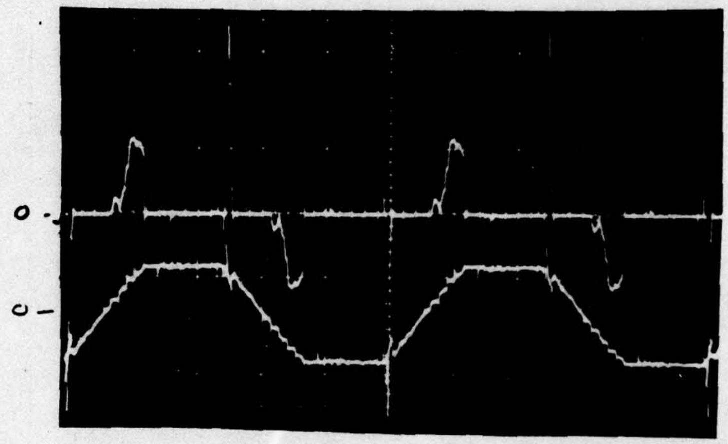
| | | | APPROVED | |

X AND Y FUNCTION CURRENTS FOR PHASE A
SHOWN WITH BASIC LINE-TO-NEUTRAL VOLTAGE
WAVEFORM OF THE FREQUENCY CONVERTER.
(POWER CENTER COMMUTATION CURRENTS INCLUDED)

13.6 KW, PF = 0.8

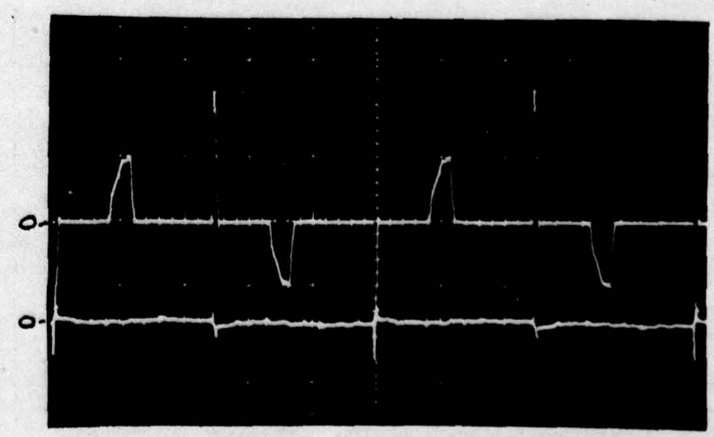
CURRENT 50A/DIV.

VOLTAGE 200V/DIV.




22KW, PF = 1.0


SHORT CIRCUIT

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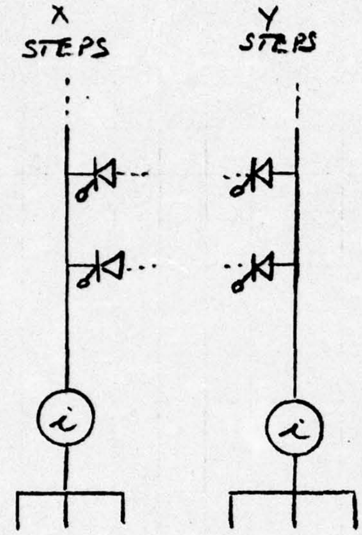
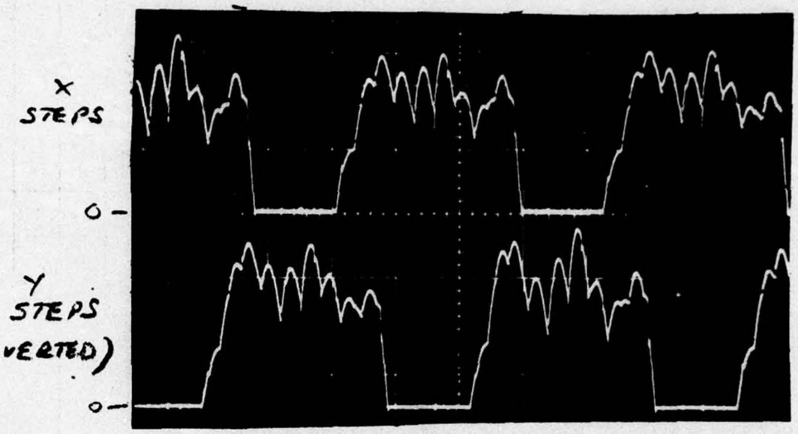
| | | | APPROVED | |

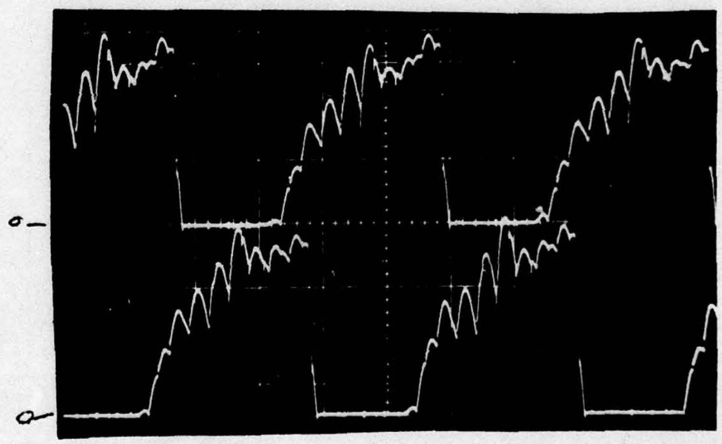
X AND Y STEP CURRENTS FOR ALL THREE PHASES



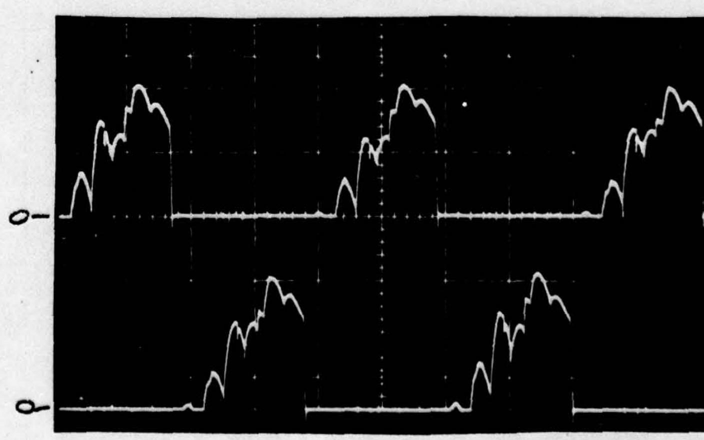

PHASE SELECTORS




NO LOAD 25 A/DIV.




11KW, PF=1.0 25A/DIV.




11KW, PF=0.8 25A/DIV.

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GENERAL MOTORS CORPORATION

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| CHECKED | | |
| APPROVED | | |

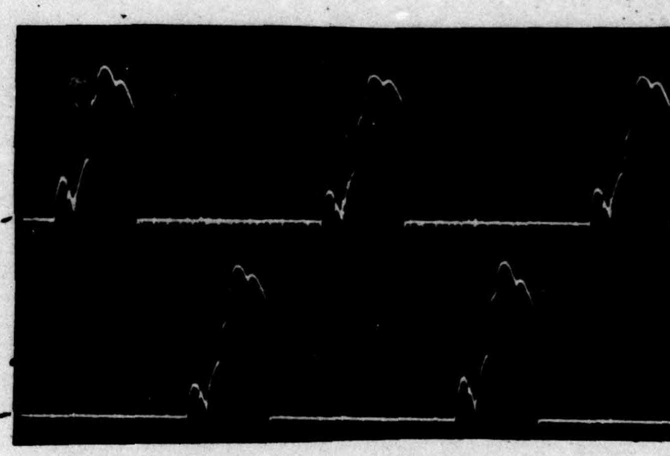
X AND Y STEP CURRENTS FOR ALL THREE PHASES

X STEPS

0-

Y STEPS (INVERTED)

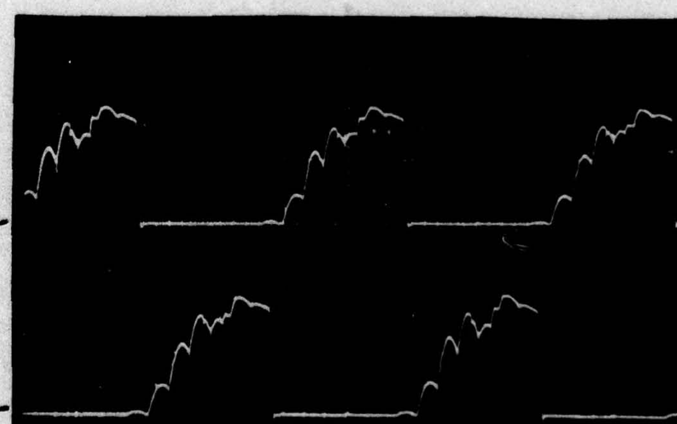
0-



13.6 KW, PF=0.8 25 A/DIV.

0-

0-



22KW, PF=1.0 50A/DIV.

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**DELCO ELECTRONICS**
GENERAL MOTORS CORPORATION

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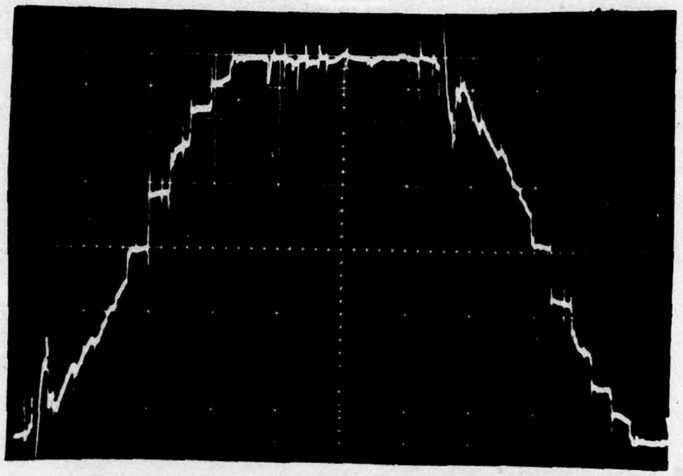
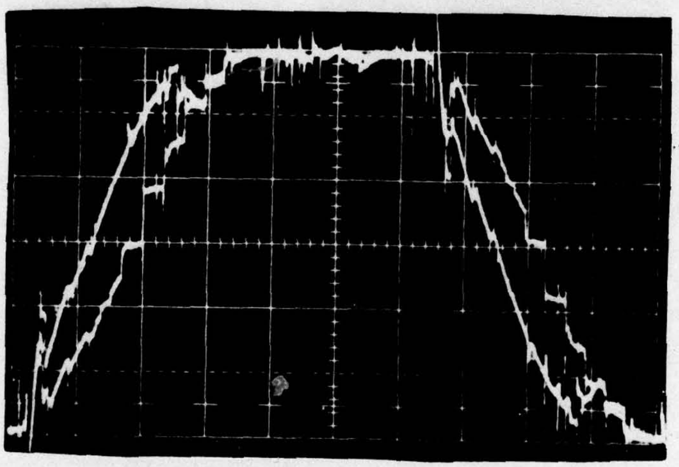
TITLE

PREPARED CORRY 1/29/7
CHECKED
APPROVED



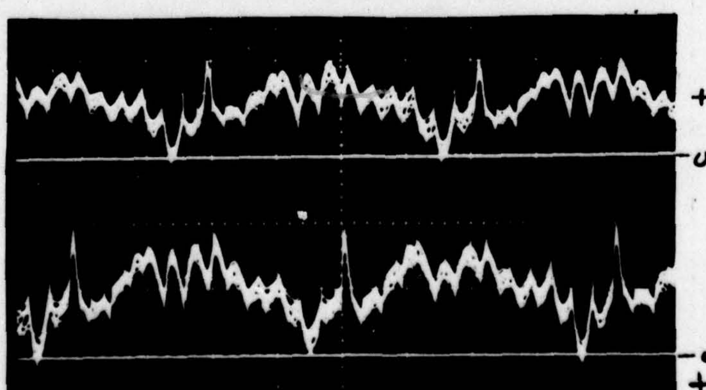
STUDY OF THE EFFECT OF LOW LOAD POWER FACTOR ON THE DISTORTIO ON THE BASIC L-T-N VOLT-AGE OF THE FREQUENCY CONVERTER.

LEFT - NORMAL WAVEFOR 11 KW, 0.8 PF THD OF OUTPUT WAVEFORM = 2.4



LOAD = 11KW + 5KVAR THD OF OUTPUT WAVE-FORM = 8%

NOTE PHASE SHIFT TO LEFT.




± VOLTAGE INPUT LINE CURRENTS FOR 11KW, PF=0.8 LOAD (60MFD. L-T-L)

↕ 50A/DIV.

↔ 200 μSEC/DIV

DISTRIBUTION:

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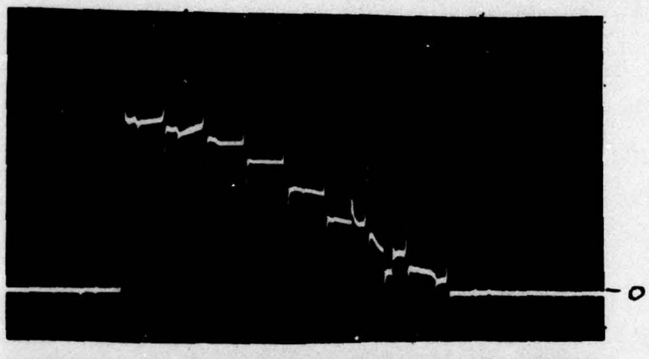
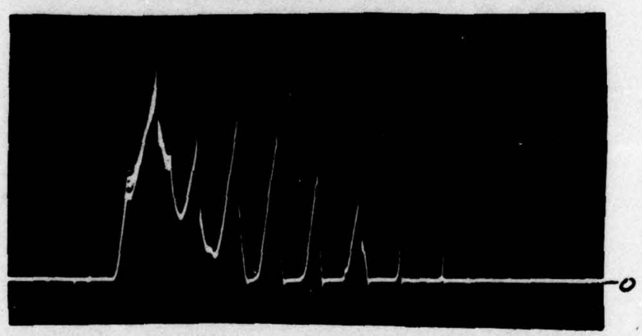
| | | CHECKED | | |
| | | APPROVED | | |

STUDY OF TRANSISTOR CURRENT AS A FUNCTION OF OUTPUT CAPACITANCE. 400HZ, THREE PHASE – 11KW, PF=0.8 LOAD HELD CONSTANT.

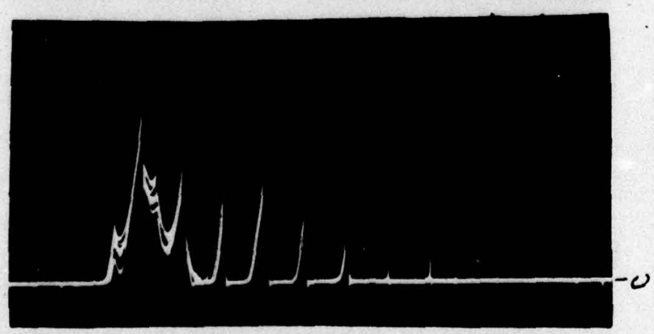
↕ 25A/DIV.
↔ 100 µSEC/DIV.




0 MFD. L-T-L




20 MFD. L-T-L

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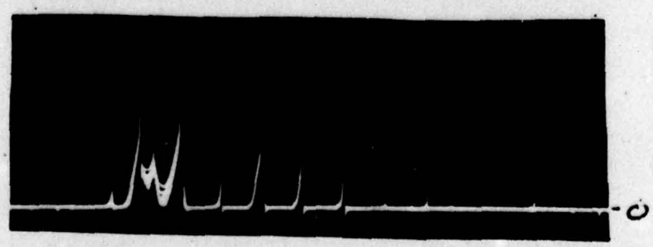


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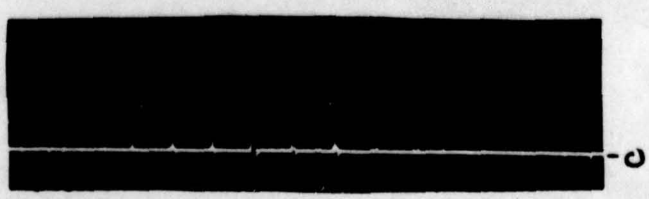


60 MFD. L-T-L

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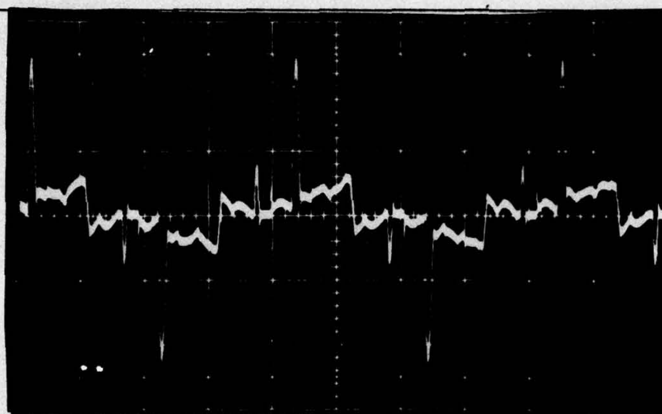
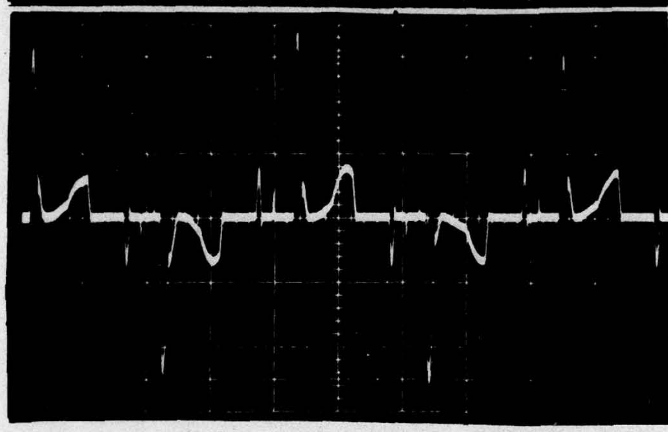




STUDY OF POWER CENTER COMMUTATION CURRENTS THRU T+, T- THYRISTORS

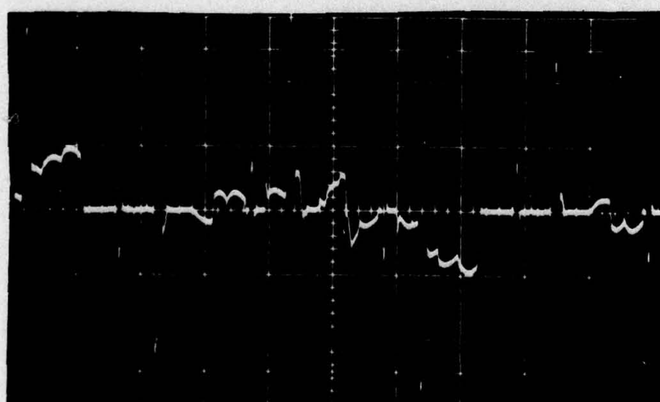
400 HZ, THREE PHASE

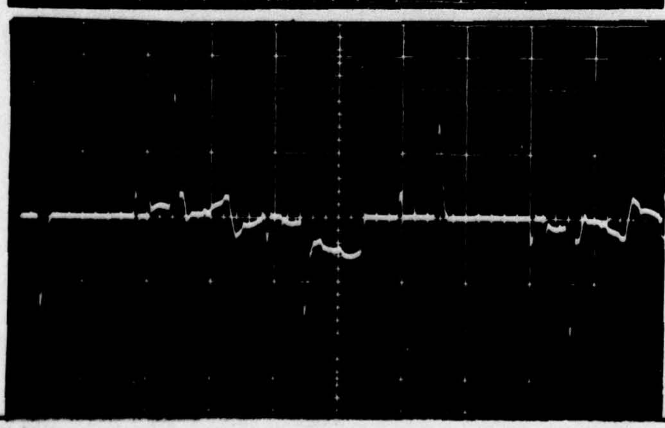
11KW, PF=0.8 LOAD

↕ 100A/DIV. ↔ 200 μSEC/DIV.

(BOOST VOLTAGE = ±25VDC)

11KW, PF=0.8 LOAD





400HZ, SINGLE PHASE

11KW, PF=0.8 LOAD

↕ 100A/DIV ↔ 200μSEC/DIV.

(BOOST VOLTAGE = ± 28VDC)

11KW, PF=0.6 LOAD

↕ 200A/DIV. ↔ 200μSEC/DIV.

(BOOST VOLTAGE = ±35VDC)

(NOTE: PEAK CURRENTS → 400A.)

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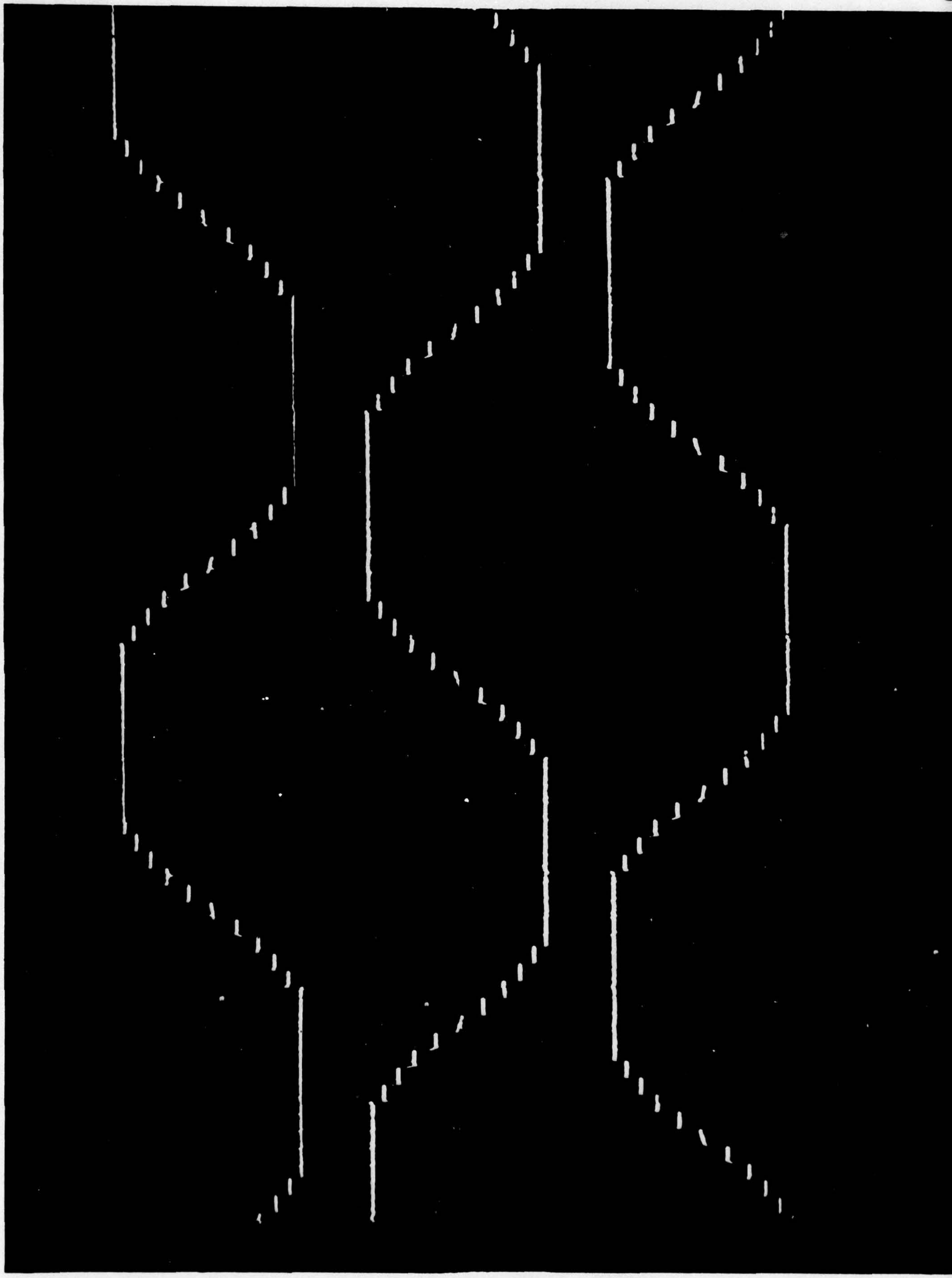
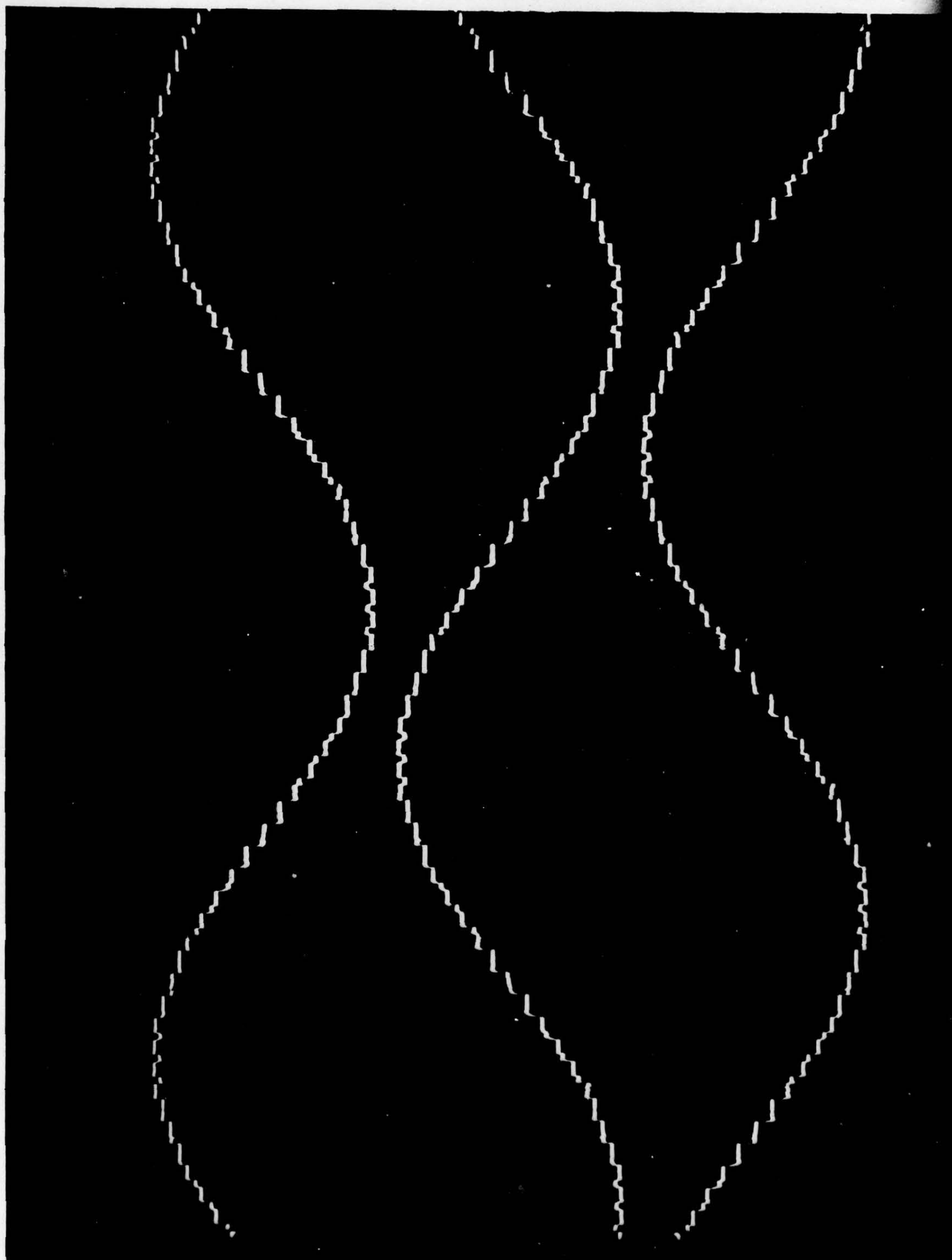


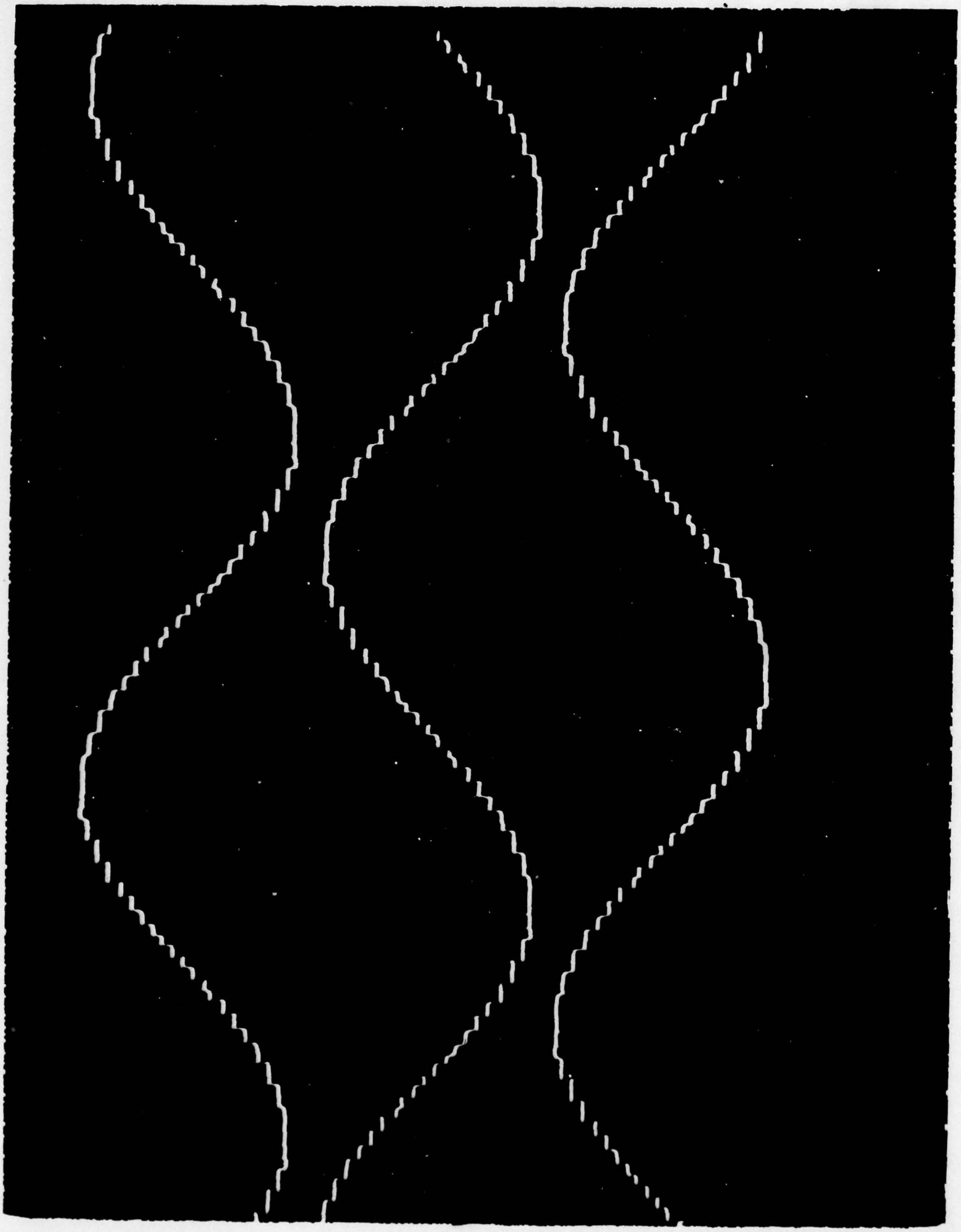
SHORT CIRCUIT

APPENDIX A



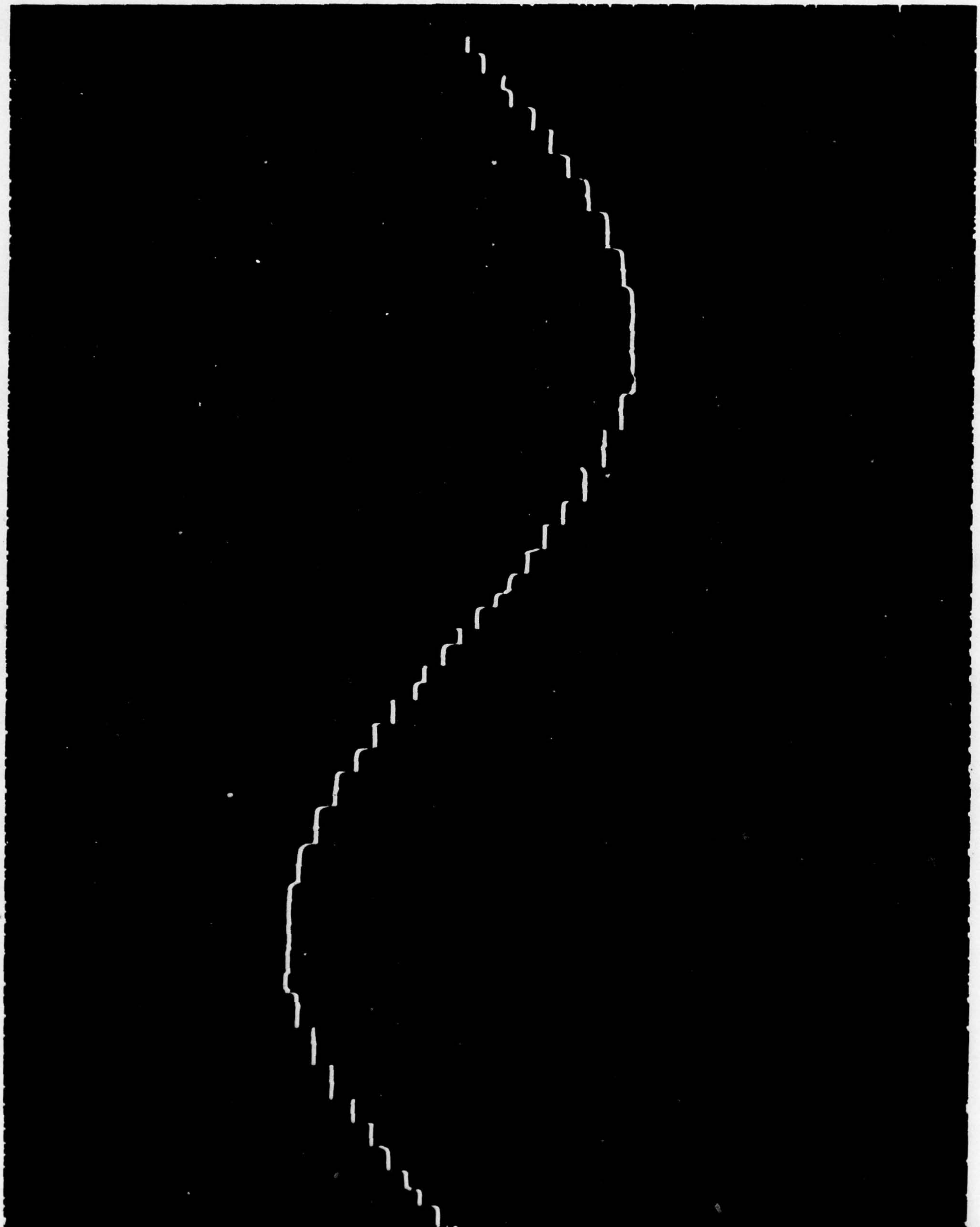
amplitude of the center are selected to produce a min-

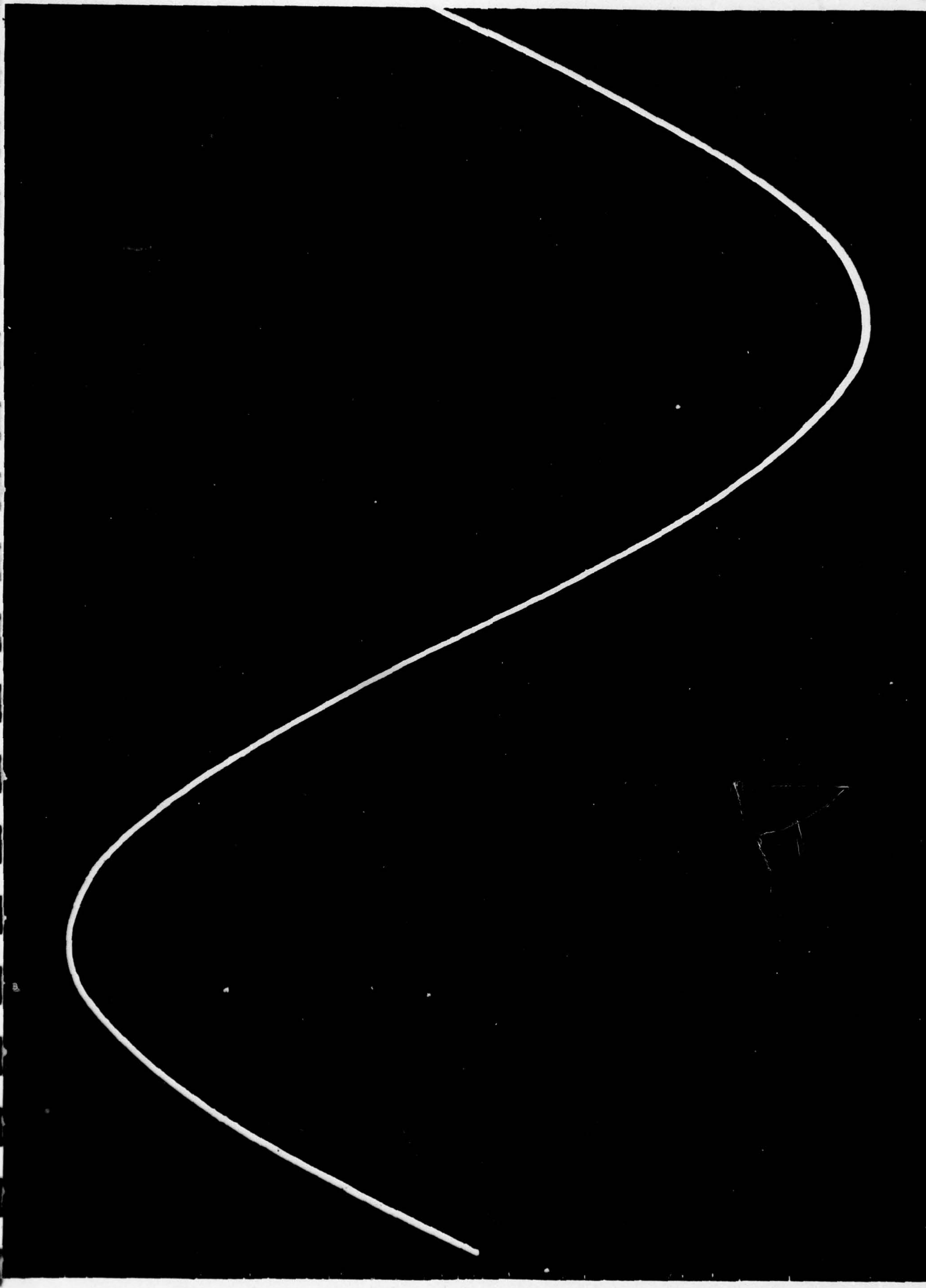
4. At any instant of time there must be a path for



LINE-TO-LINE VOLTAGES

LINE-TO-LINE VOLTAGE

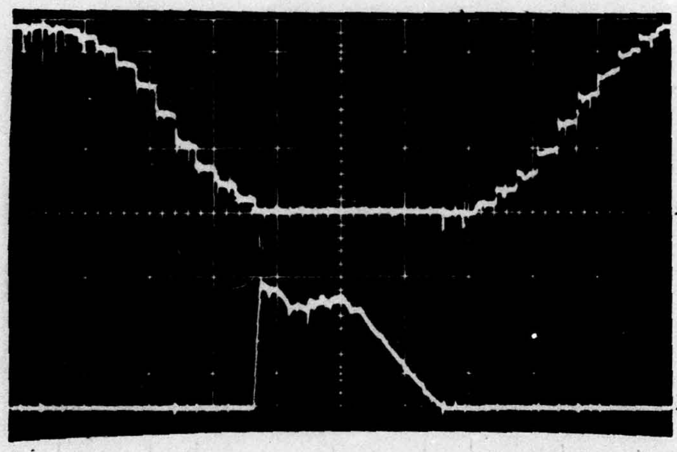




FILTERED L-T-N OUTPUT VOLTAGE THD= 0.95%

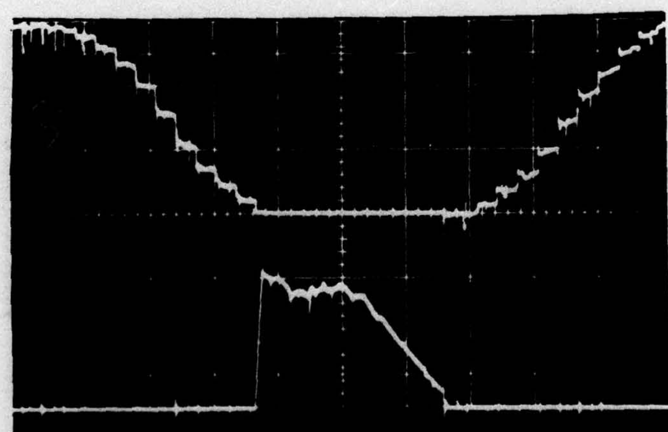
OPERATING INVERTER WITH NO P.C. COMMUTATION CIRCUIT

400 HZ, THREE PHASE
60 MFD. L-T-L
POWER CENTER ANODE VOLTAGE & CURRENT



+
—0 ↕ 100V/DIV
+
—0 ↕ 50A/DIV ↔ 200 μSEC/DIV

13KW, PF=1.0



+
—0
+
—0

16KW, PF=1.0

(UPPER LIMIT)

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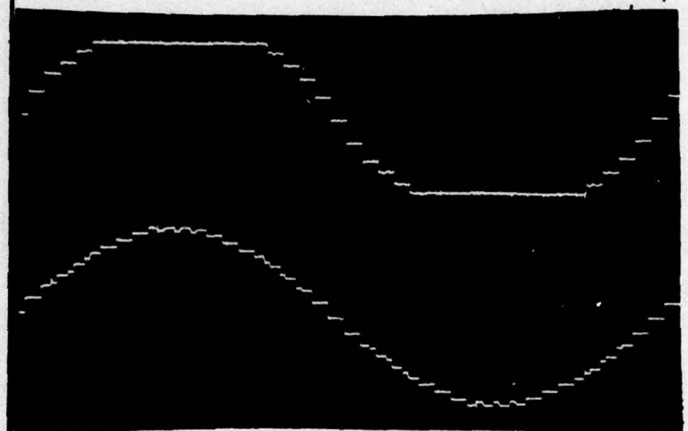
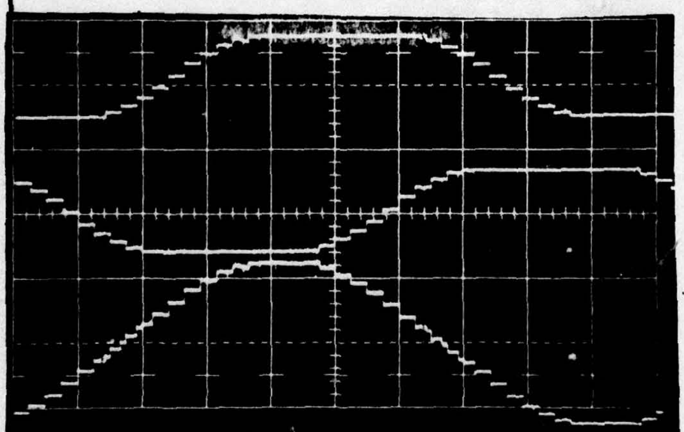
INVERTER VOLTAGE WAVEFORMS



60 HZ, THREE PHASE

UPPER TRACE - BASIC INVERTER L-T-N VOLTAGE INTO TRIPLEN ATTENUATOR.

LOWER TRACE - RESULTANT L-T-N VOLTAGE WAVEFORM AT OUTPUT OF TRIPLEN ATTENUATOR. UNFILTERED THD = 4.2%



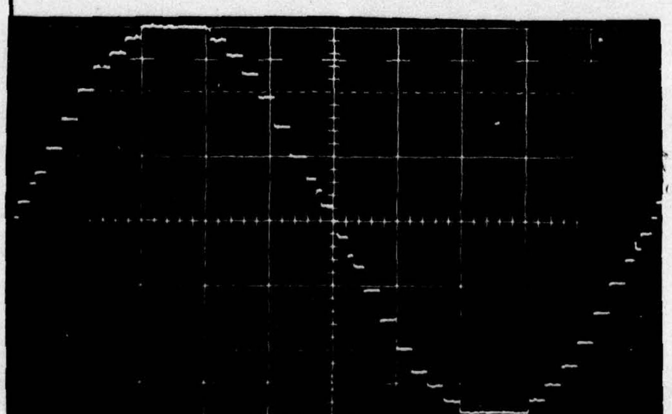
UPPER TRACES - BASIC INVERTER L-T-N VOLTAGES

$V_{AN}$

$V_{BN}$

LOWER TRACE - RESULTANT LINE-TO-LINE VOLTAGE $V_{AB}$

$V_{AB} = V_{AN} + V_{NB}$



BASIC LINE-TO-LINE VOLTAGE PRIOR TO FILTERING. THD = 4.2%

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APPENDIX B

Item 0001

CDRL Item A0002

Contract No. DAAK02-72-C-0210

APPENDIX B

# GENERALIZED THREE-PHASE WAVEFORM GENERATOR

In three-phase electrical systems, the basic expression relating a line-to-line voltage, call it g(t), to the line-to-neutral voltage, call it f(t), (assume a balanced system for this discussion) is

$$g(t) = f(t) - f\left(t + \frac{T}{3}\right) \tag{1}$$

where the three line-to-neutral voltages are displaced 120 electrical degrees, one from the other.

In three-phase electrical systems, we generally have the following properties of f(t) and g(t)

| | | | | |
|---|---|---|---|---|
| $f(T+t) = f(t)$ | (2a) | $g(T+t) = g(t)$ | (periodic) | (2b) |
| $f\left(\frac{T}{2} + t\right) = -f(t)$ | (3a) | $g\left(\frac{T}{2} + t\right) = -g(t)$ | (half-period symmetry) | (3b) |
| $f(0) = 0$ | (4a) | $g\left(\frac{T}{12}\right) = 0$ | | (4b) |
| $f(-t) = -f(t)$ | (5a) | $g\left(\frac{T}{12} - t\right) = -g\left(\frac{T}{12} + t\right)$ | (symmetric relative to $\frac{T}{12}$) | (5b) |
| | | $g(t) + g\left(t + \frac{T}{3}\right) + g\left(t + \frac{2T}{3}\right) = 0$ | | (6) |

The 'neutral,' N, against which f(t) is measured, need not be constant; it can contain any or all of the 3nth, n=0, 1, 2, ..., harmonics of the fundamental frequency $\frac{1}{T}$.

It is important to note that (though it is not generally appreciated) property (5a) does not have to hold for property (5b) to hold.

The purpose of the following is to establish that: Given a waveform g(t) with properties 2b-5b and 6, and given the task of creating g(t) from some f(t) via Equation 1, then, in addition to the usual properties of f(t) cited in Equations 2a-5a, it can be shown that we have the following remarkable property.

Property 1: We can assign arbitrary values to any set of points of f(t) with measure $\frac{T}{6}$ in the interval $\left(0, \frac{T}{2}\right)$, and the remaining points of f(t) in this interval can be properly chosen to construct g(t) exactly.

This unusual property of f(t) has powerful implications, since it allows considerable lattitude in mechanizing the construction of desired line-to-line waveforms in a 3-phase electrical system by means of line-to-neutral waveforms whose shapes are not necessarily constrained to be the same as that of the line-to-line waveforms.

To clarify this notion, let us consider a special form for f(t).

Let the functions a(t), b(t), and c(t) be arbitrary over the interval $0 \le t < \frac{T}{6}$ and be zero elsewhere, and define

$$f(t) = a(t) \qquad 0 \le t < \frac{T}{6} \tag{7}$$

$$f\left(t + \frac{T}{6}\right) = b(t) \qquad 0 \le t < \frac{T}{6}, \ \frac{T}{6} \le \left(t + \frac{T}{6}\right) < \frac{2T}{6} \tag{8}$$

$$f\left(t + \frac{T}{6}\right) = c(t) \qquad 0 \le t < \frac{T}{6}, \ \frac{2T}{6} \le \left(t + \frac{2T}{6}\right) < \frac{3T}{6} \tag{9}$$

These equations define f(t) on the interval $\left(0, \frac{T}{2}\right)$, and properties (2a) and (3a) define it for all other t.

From Equation (1), it follows that

$$g(t) = a(t) - c(t) \qquad 0 \le t < \frac{T}{6} \tag{10}$$

$$g\left(t + \frac{T}{6}\right) = b(t) + a(t) \qquad 0 \le t < \frac{T}{6}, \ \frac{T}{6} \le \left(t + \frac{T}{6}\right) < \frac{2T}{6} \tag{11}$$

$$g\left(t + \frac{2T}{6}\right) = c(t) + b(t) \qquad 0 \le t < \frac{T}{6}, \ \frac{2T}{6} \le \left(t + \frac{2T}{6}\right) < \frac{3T}{6} \tag{12}$$

These three equations define g(t) on the interval $\left(0, \frac{T}{2}\right)$, and properties (2b) and (3b) define it for all other t.

Now we ask, what constraints are imposed on the functions a(t), b(t), and c(t) so that Equations (10)—(12) meet the requirements of Equation (6)?

By having constructed f(t) in this special way, the resulting Equations (10)—(12) make it clear that any one of the functions a(t), b(t), or c(t) can be specified arbitrarily, and the remaining two derived to construct g(t) exactly. In fact, without such a specification, there are an infinite number of solutions to Equations (10)—(12).

To check this observation, let us assume that b(t) is arbitrary. Then we have

$$a(t) = g\left(t + \frac{T}{6}\right) - b(t) \tag{13}$$

$$c(t) = g\left(t + \frac{T}{3}\right) - b(t) \tag{14}$$

and

$$a(t) - c(t) = g\left(t + \frac{T}{6}\right) - g\left(t + \frac{T}{3}\right) = g(t) \tag{15}$$

as it should. (Note that the last step depended upon the property expressed by Equation (6), where we make the substitution

$$g\left(t + \frac{2T}{3}\right) = -\, g\left(t + \frac{T}{6}\right).\ )$$

A more general statement of this observation is as follows: For each point t in the interval $\left(0, \frac{T}{6}\right)$ any one of the functions a(t), b(t), or c(t) can be specified arbitrarily, and the other two assigned their value according to Equation (6). In this statement, the choice as to which of the functions is assigned an arbitrary value is itself arbitrary for each t in $\left(0, \frac{T}{6}\right)$. The generalized Property 1 follows directly.

Using the special definitions of Equations 7—9, and properties 2a and 3a, the line-to-neutral voltages for the three phases (each displaced from the other by $120^{\circ}$) are as shown in Figure C-1.

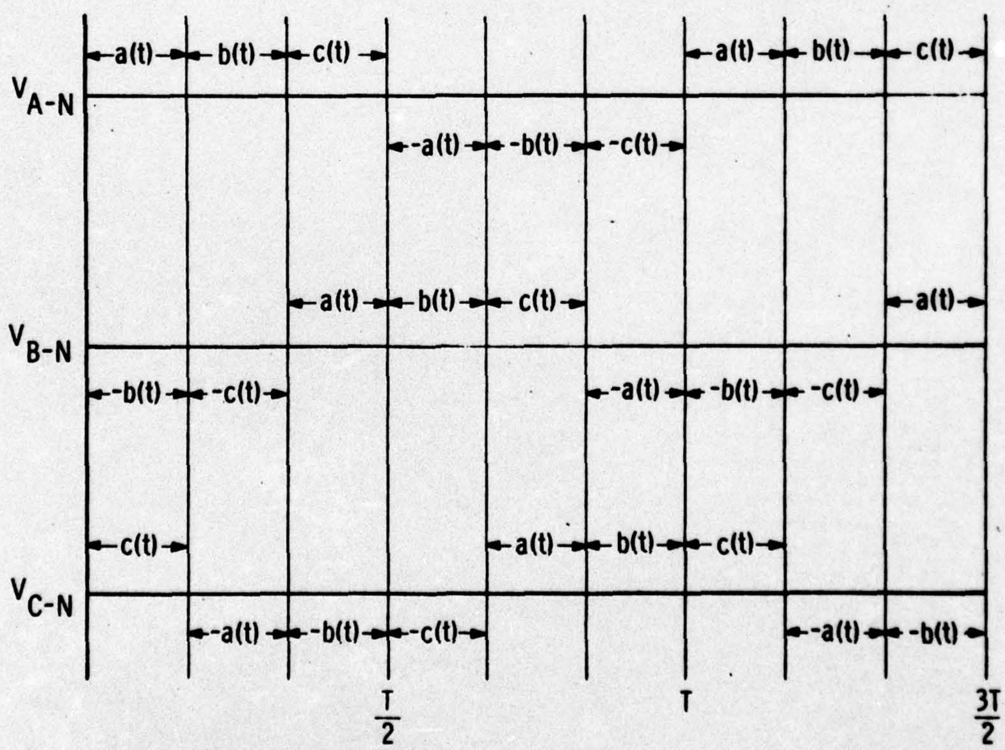



Figure C-1 Line to Neutral Voltage Construction

We note that at any instant of time, a(t) and c(t) are simultaneously negated (a minus sign in front of each) or not; when they are negated, b(t) is not; when they are not negated, b(t) is. Further, we note that the negation alternates between b(t) and [ a(t), c(t) ] every $\frac{T}{6}$ units of time.

These observations allow us to make a general circuit configuration as shown in Figure C-2.

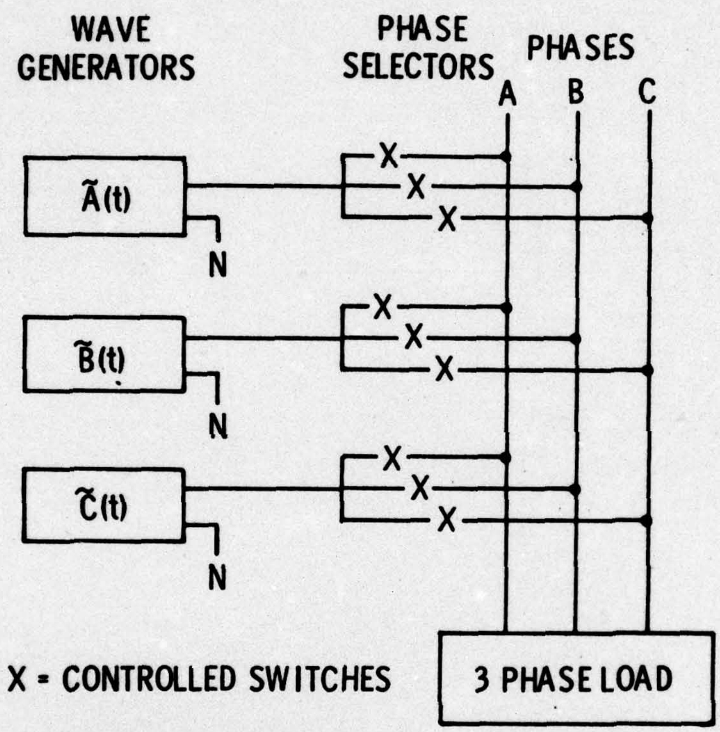



Figure C-2 General Circuit Configuration

The wave generators $\tilde{A}$(t), $\tilde{B}$(t), and $\tilde{C}$(t) produce the functions a(t), b(t), and c(t), respectively, and repeat these functions every $\frac{T}{6}$ units of time with alternating polarity (relative to the neutral N), synchronized according to Figure A-1. Each generator feeds its line-to-neutral voltage into each phase according to the timing indicated in Figure A-1 (each generator feeds only one phase at a time). The phase selection is accomplished by means of (the indicated) switches. (Note: $\tilde{A}$(t) could generate c(t) followed by -a(t), and repeat this every $\frac{T}{3}$ units of time, and $\tilde{C}$(t) could generate c(t) followed by -a(t), repeating this every $\frac{T}{3}$ units of time. This is the way we do it in practice, but for ease of discussion the former method is used throughout this paper.) Thus, any g(t) with properties 2b—5b and 6 can be constructed

via the system specified by Figures A-1 and A-2. The period T is fixed directly by g(t). The functions a(t), b(t), and c(t) are selected according to g(t) via Equations (10) and (12), and within the lattitude provided by Property 1, they are selected to minimize (or some optimization of) the hardware requirements.

# APPENDIX C

Item 0001

CDRL Item A0002

Contract No. DAAK02-72-C-0210

APPENDIX C

# A NEW INVERTER CONCEPT

T. M. Corry

Delco Electronics Division, General Motors Corporation
Goleta, California

## ABSTRACT

A rational method for using switching circuits to produce precision three-phase sine wave power from dc or ac power sources has been developed. A three-phase sine wave format is considered to be composed of voltage segments consisting of stepped waves and square waves generated by separate circuits and combined on a three-phase line to produce voltage waveforms with a total harmonic content of 4% prior to filtering. The stepped portions of the wave, called X and Y functions, are generated by a tapped autotransformer and appropriate switches. Only about 20% of the power is generated in the form of steps. A simple circuit that generates a square wave voltage called the "center" function, handles more than 80% of the inverter power. The inverter has the following characteristics: high input power factor (typically 0.9 to 0.95); low output impedance; can energize nonlinear loads without significant change in total harmonic content; and easy to parallel because of low energy storage in the output filter. The inverter has an efficiency of 88-93% and weighs about 120 lb (breadboard). Power rating is 10 kW with 200% overload capacity and output frequency is 60 or 400 Hz.

My invention, Patent No. 3,725,767 describes a new concept in the organization of power switching circuits to produce low harmonic content three-phase power. The first part of this paper reviews the conceptual thinking that led to the development of the inverter and describes the patented circuits. The second part summarizes the development effort on a 10 kW breadboard inverter built under contract DAAK 02-72-C-0210 for the U.S. Army Mobility Equipment Research and Development Center (MERDC).

Rather than starting with known inverter concepts such as square wave summing, pulse width modulators, or cycloconverters, and designing them to produce three-phase sine wave power, I started by reviewing the art, determining some basic characteristics preferred in an inverter, and commencing a waveform analysis.

Since it was desired to develop a light-weight unit, the initial criteria were to:

1. Have as much power as possible go from the power source to the load without passing through transformers. This criterion helps minimize iron and copper weight and enhances efficiency.
2. Utilize the power switches to create close approximations to sine waves. This criterion helps to minimize energy stored in the output filter.

For purposes of computer optimization and circuit analysis, this criterion established the frame of reference for waveform construction:

3. Construct the waveform from line-to-neutral.

These criteria and the computer waveform study led to the three-phase waveform design shown in Figure 1. Although these approximations of sine waves appear to be crude, the total harmonic content (THD) is only 6.4% and the THD of the resultant line-to-line voltage is 3.2% because the triplen harmonics are not present.

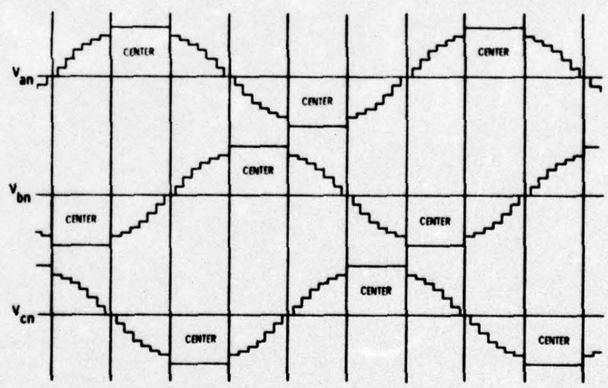



Figure 1. Three-phase Sine Wave Format Designed By The Author In Developing The New Approach to Inverter Design.

This three-phase format has several important properties. $V_{an}$, $V_{bn}$, and $V_{cn}$ are line-to-neutral voltages. Each half-cycle consists of a 60° section of voltage steps rising toward the peak, a 60° section of constant amplitude voltage, and a 60° section of voltage steps descending to zero voltage. Each successive half-cycle is a reversed reproduction of the previous one. For any number (n) steps, the amplitude of each step, the angle of occurrence for each step, and the

amplitude of the center are selected to produce a minimum harmonic content line-t-line voltage. For any 60° interval the polarities of the center portions and the stepped portions of the waves are opposite. The polarities of the two stepped portions are the same, and the polarities of the center and steps rotate at a frequency three times the frequency of the line voltages.

The usefulness of these properties to the circuit designer are:

- The flat top center portions of the wave can be formed by a simple switching circuit. If the voltage is the proper magnitude, the switch can be connected directly to the three-phase line without the use of transformers. More than 60% of the wave energy is contained in the center portion and this energy can be handled at 99% efficiency with very little investment in weight.
- Transformers needed in step-forming circuits handle only 40% of the power and operate at three times the frequency of the inverter output voltages.
- A block diagram that organizes the inverter on the basis of the waveform design can be constructed as illustrated in Figure 2. For a 400 Hz three-phase inverter, the output voltages are composed of three 1200 Hz functions combined sequentially on the three-phase line to produce low harmonic voltages.

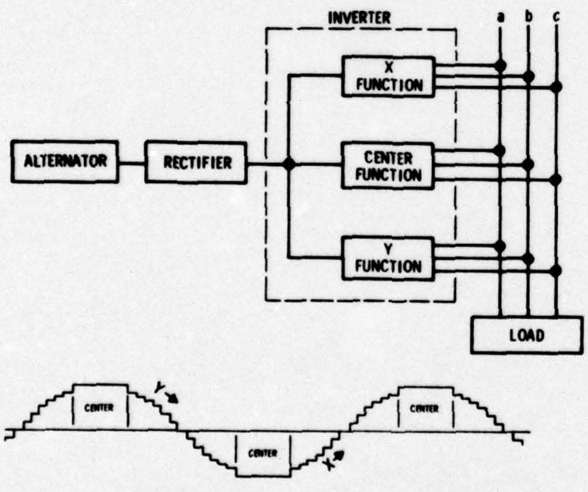



Figure 2. Block Diagram Of Alternator, Rectifier, And Inverter X, Y and "Center" Function Generators.

The circuit designer can then devise circuits that perform the functions of the inverter block; namely, create X, Y and "center" wave functions. This is a new freedom the designer does not have with other inverter approaches. The block functions can be selected and optimized relatively independently of each other.

There are several circuits that can generate X, Y and "center" functions; two additional guidelines help in defining these circuits:

4. At any instant of time there must be a path for current flow in either direction at a voltage level that preserves the sine wave approximation. In other words, never interrupt the load current. This guideline assures operation of the inverter with leading, lagging, or unity power factor loads.

5. Use double-bus switching techniques for changing voltage levels.

The three functions that must be produced by the blocks that compose the inverter are illustrated in Figure 3. Basic circuits for producing the X, Y and "center" functions are also defined. The X and Y functions are voltage steps of the same polarity with one set ascending while the other set descends. The steps can be produced by using a tapped autotransformer energized by a square wave that is three times the inverter output frequency. Two sets of switches are connected to the transformer taps; one set produces the X function, and the other the Y function. The "center" wave can be generated by a square wave switching circuit that operates in synchronism with the X, Y functions but that is 180° out of phase.

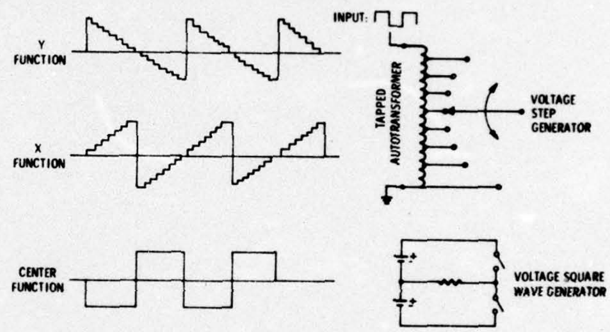



Figure 3. Waveform Definitions And Circuits That Can Generate the X, Y And "Center" Functions.

All that is needed now is to design these two simple circuits within the constraints of guidelines 4 and 5 and to connect the circuits to the inverter output lines. Figure 4 shows how the function generator circuits can be configured and connected to produce the new inverter concept. The circuit consists of a dc voltage source, "center", X and Y function circuits, and phase selectors. The "center" function generator is a three-phase thyristor bridge circuit. Most of the inverter power passes directly from the power source through the center switches and into the load; this is a very low impedance, high efficiency path. The major losses are the conduction losses of the thyristors. The remaining power is handled by the step autotransformer circuit. Step voltage power passes from the power source through a thyristor square wave switching circuit that energizes the autotransformer through the appropriate X and Y function voltage levels, and to the proper output line by means of the phase selectors. The impedance of this circuit consists of several semiconductors in series with the transformer leakage inductance. The total inverter circuit shown consists primarily of thyristors which require commutation to turn off. The currents of the step thyristors pass through transistors A or B. Commutation is accomplished by turning the

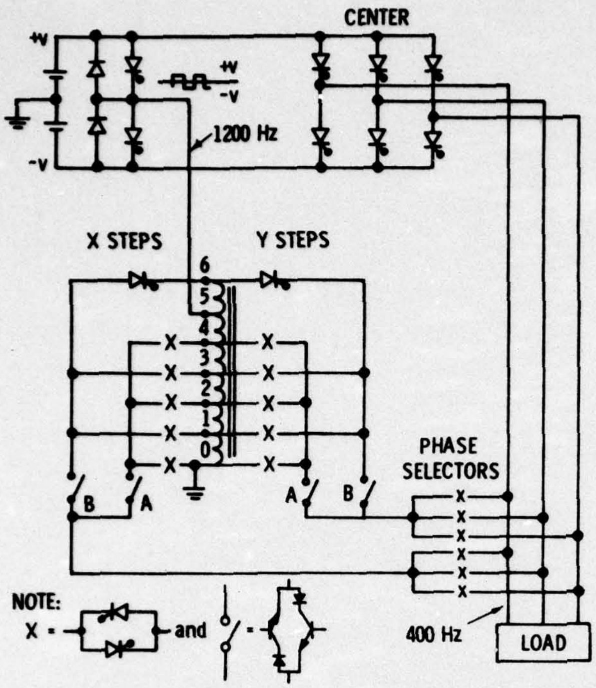



Figure 4. Basic Inverter Circuit

conducting transistor off and starving the series thyristor. Starvation commutation has proven to be efficient and very reliable, and all step changes are made using this process. The center function thyristors are commutated by the sixth level voltage on the autotransformer. Reverse commutation current is switched through the commutation thyristor, transistor B, the phasor, and finally the conducting "center" function thyristor. Capacitor commutation circuits are not used in this particular circuit configuration, but they can be used to turn off step or power center thyristors if that method is preferred. Transistors can be used throughout the inverter rather than thyristors. Triacs or thyristor-diode bridges can be substituted for the bilateral connected thyristors.

The circuit concept of Figure 4 has made possible inverter hardware with these important characteristics:

- Light weight - Output voltage waveforms with total harmonic content less than five percent at the output of the power switches can be constructed with low weight investment in filters and transformer iron and copper. In the following paragraphs it will be shown that more than 80 percent of the power can be made to flow through the "center" function generator of the inverter. Consequently, the autotrans- carries less than 20 percent of the inverter power.

- High Efficiency - More than 80 percent of the power passes through the basic inverter at close to 99 percent efficiency. The overall efficiency of the MERDC inverter peaks at about 92 percent.

- Low Output Impedance - This characteristic, combined with the low total harmonic content waveform, makes possible small output filters with low energy storage. The result is an inverter that is easy to parallel and that can energize nonlinear loads. In addition, inverter regulation is low. It has good transient response characteristics.

- High Input Power Factor - Since this inverter is the dc-link type, it requires rectifiers at the input for operation on ac power lines. Three-phase full wave rectifiers have power factors that range from 0.90 to 0.95.

This new inverter concept allows the designer to experiment with waveshape designs with only minor power circuit changes. Various waveshapes have different impacts on the inverter circuit performance and output filter design. An abstract description of the concepts that resulted in the basic inverter organization was developed shortly after my observations that X, Y and "center" functions can be used to create three-phase sine waves were made. Briefly, in a three-phase system, the line-to-line voltage defined g(t), can be constructed exactly by a line-to-neutral voltage, defined f(t), that has the same period as g(t) and an interesting property: one-third of a half-cycle of f(t) is specified arbitrarily, and the remaining two-thirds of the half-cycle are derived according to g(t). The mathematical proof of this fact verifies that the center 60-degree portion of each half-cycle of the line-to-neutral wave can be set arbitrarily to a constant value, and then the left and right portions selected according to g(t). The waveform design studies revealed that this procedure can produce a pure line-to-line sine wave and also result in a good approximation of a line-to-neutral sine wave.

With these insights, the designer can then establish additional guidelines that will help in building useful inverters:

6. Select waveforms that allow safe commutation times for thyristors in the step-former, "center" function and phase sector circuits.

7. Use energy handling components in preference to energy storage components. For example, when tradeoff permits, increase transformer weight or number of switches if it will lead to reductions in filter capacitor and inductor weight.

8. Design the voltage waveforms with harmonics distributed so as to minimize energy storage in the output filter.

In designing waveforms for this inverter, one has considerable control over the distribution and magnitudes of the harmonics. The designer can minimize line-to-line or line-to-neutral voltage total harmonic distortion within various constraints such as the number of voltage levels, the width of the "center" function, the widths of the voltage steps, or multiple constraints such as number of steps and minimizing selected harmonics. Each optimization exercise influences the inverter switching circuits and output filter.

An analysis of waveforms was made in which the computer was asked to construct line-to-neutral voltages that produced line-to-line voltages with minimum harmonic content as a function of the number of voltage taps on the inverter autotransformer. The following sets of conditions were used: (a) center width equal to 60° with unconstrained step widths, (b) unconstrained center and step widths, (c) unconstrained center and equal step widths, and (d) equal step widths with center width constrained to be a multiple of a step width.

Figure 5 shows total harmonic content of the line-to-line voltages as a function of autotransformer steps for the conditions defined in (b). The chart shows that the inverter can produce unfiltered output voltages with total harmonic content of 2.5 percent by using seven transformer steps.

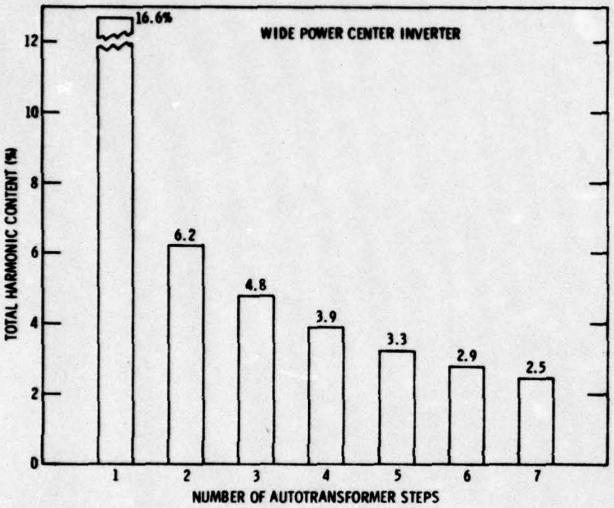



Figure 5. Total Harmonic Content Versus The Number Of Taps On The Step Transformer. No Constraints Were Placed On Center and Step Widths.

The waveform selected for the MERDC inverter was defined on the basis of constraints in (d) and is illustrated in Figure 6. This waveform has these desirable properties. The flat top portion of the wave is 99° wide and allows the "center" function circuit to deliver more than 80 percent of the power. The total harmonic content of the line-to-line wave is 4.2 percent; the MERDC requirement defines a maximum THD of five percent. Equal step widths with the center 11 times the width of a step allows relatively simple logic circuitry for triggering power switches. All harmonics greater than one percent are clustered around the 41st harmonic (Figure 7). This property helps in the output filter design. The undesirable property of this wave is that it contains 16.02 percent third harmonic. However, this harmonic and all multiples of the third can be removed easily by a triplen attenuator that also functions to filter noise.

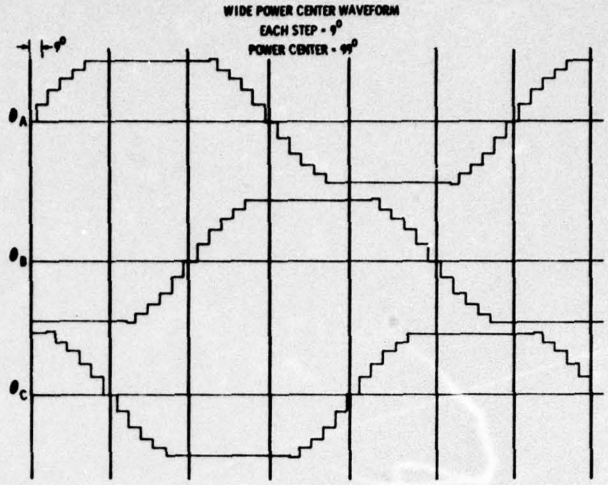



Figure 6. Waveform Selected For The MERDC Inverter

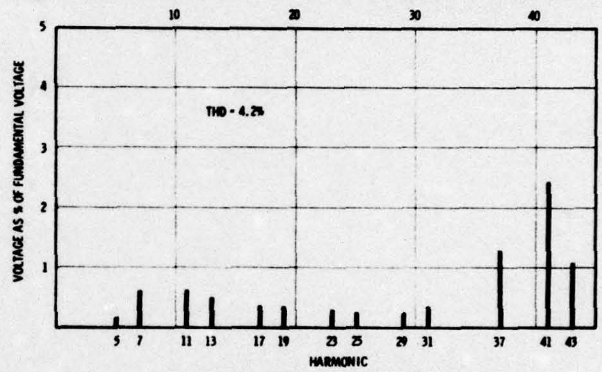



Figure 7. Harmonic Content Distribution Of The Line-To-Neutral Voltage Has 16.02% Third Harmonic, But This And Other Triplen Voltages Are Eliminated In The Output Attenuator.

The objective of the MERDC project was to develop a 60 Hz - 400 Hz 10 kW inverter to operate from an Army turbo-alternator system. A simplified schedmatic diagram of the inverter designed for MERDC is given in Figure 8; elements of the circuit not pertinent to this discussion are not shown. Differences between the MERDC circuit (Figure 8) and the basic inverter (Figure 4) starting from the top and working down are:

- A commutation circuit for the thyristors that drive the step autotransformer has been added. The maximum current that this circuit must commutate is about one ampere, the magnetizing current of the transformer. Load current does not flow through the transformer during this commutation interval.

- A capacitor has been added in series with the top level of the autotransformer. This addition allows the "center" function circuit commutation current to bypass the step commutation transistors, and increases the current capability of the inverter.

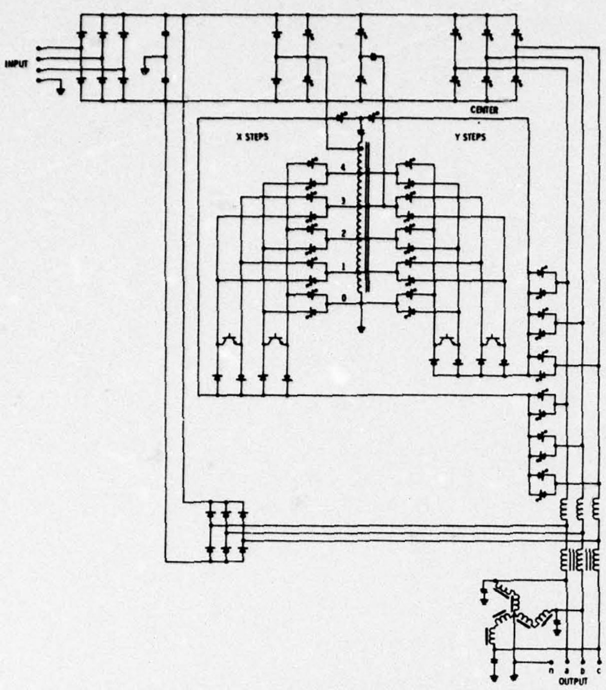



Figure 8. MERDC Inverter Schematic Diagram

- A diode bridge has been added (on lower left of the schematic) to enable the inverter to operate at any power factor from unity to zero, leading or lagging. For power factors greater than 0.76, reactive energy circulates from one phase to another through the autotransformer. For power factors below 0.76, the reactive current also returns through the diode bridge which is in parallel with the "center" function circuit thyristors.

- Near the output of the circuit are shown a triplen attenuator and a zig-zag transformer. The attenuator offers a high impedance to the third harmonic. The zig-zag autotransformer is designed to carry the line-to-neutral load unbalance, and maintains phase voltage balance for unbalanced loads. Line-to-line loads do not require the actions of the attenuator or the zig-zag transformer.

Figure 9 shows oscilloscope photographs of the unfiltered power voltages generated by the MERDC inverter. The three-phase composite voltages as generated by the X, Y and "center" function circuits are shown in Figure 9a. This waveform is virtually identical to that designed by the computer optimization program. The center is 99° wide and each step is 9° wide. Resultant line-to-neutral and line-to-line output voltages are shown in Figures 9b and 9c. The total harmonic content of these waveforms is 4.2 percent. Individual harmonic magnitudes are very close to the magnitude listed in the computed design.

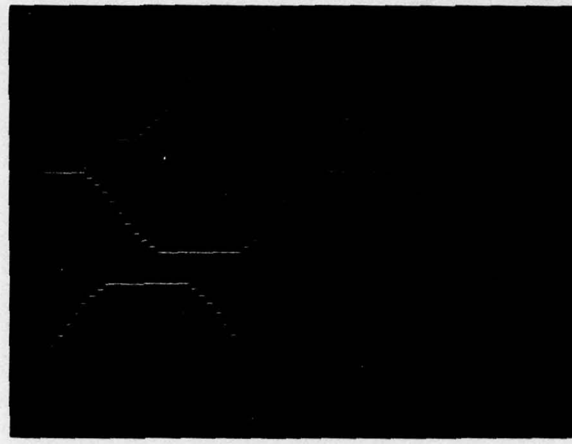


Figure 9a. Three-phase Composite Voltages Generated By The X, Y, And "Center" Function Circuits.

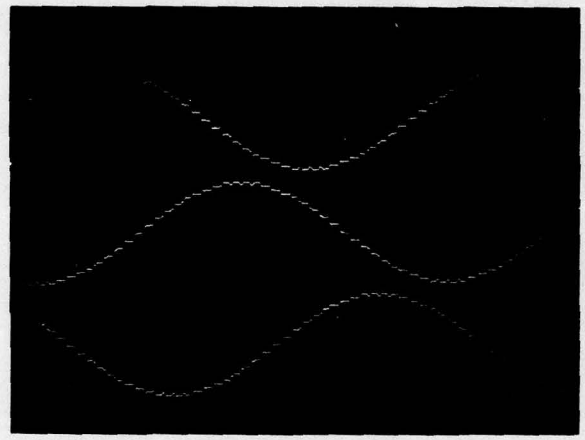


Figure 9b. Line-To-Neutral Output Voltages

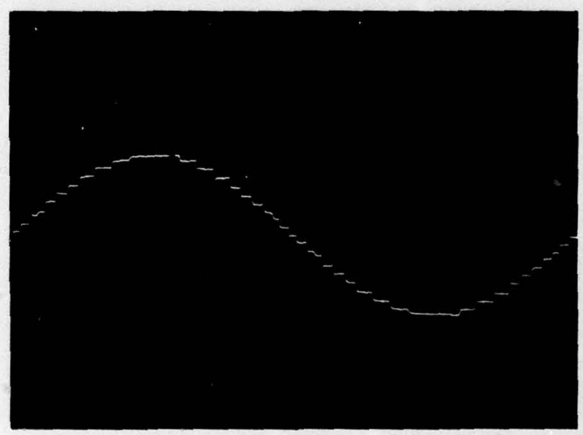


Figure 9c. Line-To-Line Output Voltage

Figure 9. MERDC Inverter Unfiltered Power Voltages

Because of the ultimate requirements for light weight and low cost for production inverters, it was decided not to use conventional stud-mounted or disc-type thyristor assemblies. Figure 10 illustrates a preferred thyristor assembly compared to two equivalent stud-mounted thyristors. The improved assembly uses two passivated 110 Arms thyristor chips attached to beryllium oxide insulators soldered to a copper base. The assembly is coated with epoxy resin, with power and gate leads brought out the top. The advantages of this approach are lighter weight and lower inverter assembly costs. The package can be mounted directly to an uninsulated heat sink. Mica insulating washers are eliminated and the need to have access to both sides of the heat sink is eliminated. These advantages are achieved with no increase in thermal impedance from the thyristor junction to heat sink. A semiconductor read-only memory is used to control the firing sequence of all inverter power switches. This device replaces TTL logic and significantly reduces logic circuitry and cost.

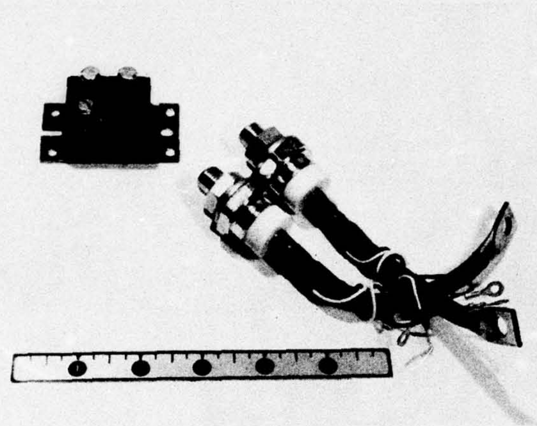


Figure 10. Comparison Of Stud-Mounted Thyristors With Insulated Base Plate Type

Figure 11 shows the assembly of the center thyristors on the heat sink structure. Eighty percent of the in-inverter power flows through this simple power switch circuit at 99 percent efficiency. Installation of the thyristors requires only a screwdriver for bolting the copper flanges to the heat sink and for connecting the power leads.

A top view of the 10 kW inverter breadboard is shown in Figure 12. The circuit breaker and alternator field control circuits are not included in the weight tabulation below.

| | Weight (lb) | Percent of Total Weight |
|---|---|---|
| Power Assembly | 22 | 18 |
| Transformer and Inductor iron and copper | 46.7 | 38.5 |
| Aluminum heat sink and structure | 50 | 41 |
| Electronics | 3 | 2.5 |
| TOTAL | 121.7 | 100.0 |

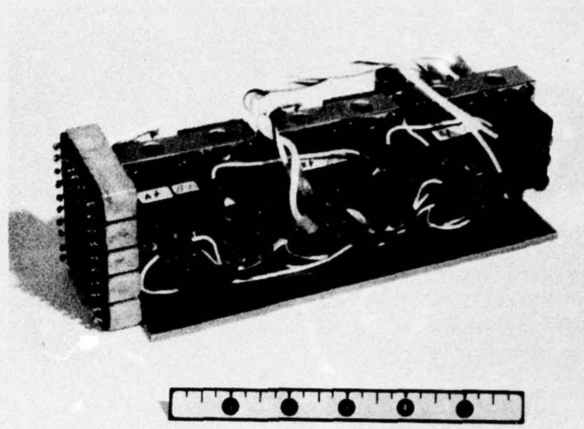


Figure 11. "Center" Function Circuit Thyristors Assembled On Heat Sink.

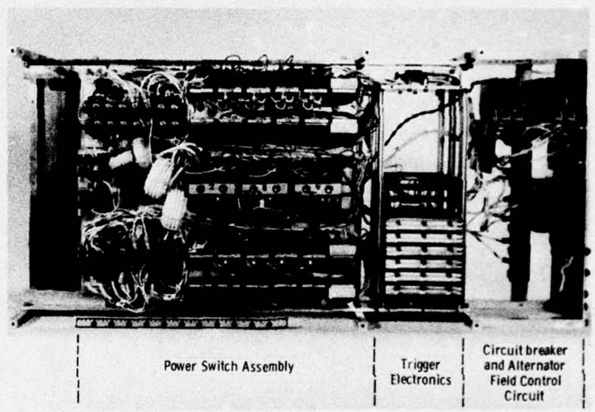



Figure 12. 10 kW Inverter Breadboard (Top View)

Figure 13 is a rear view of the inverter showing the output filter and zig-zag transformer mounted on the bottom of the heat sink.

The turbo-alternator inverter transient response to a step change from no load to full load with the inverter frequency at 60 Hz is shown in Figure 14.

Results of the tests thus far conducted on the MER-DC inverter are given in the Appendix.

In summary, a new way of looking at the problem of generating three-phase sine waves with semiconductor power switches has been described. Several circuits have been defined that can generate X, Y and "center" functions, the most promising of which was discussed in this paper. The resultant inverter has these useful properties: high input power factor, continuous input dc current, low harmonic content waveform into output filter, can energize nonlinear loads, and can energize unbalanced loads with differing power factors from unity to zero, leading or lagging. Because energy storage in the output filter is low the inverter is easy to parallel and there is no deterioration in waveform quality with step changes in load.

Figure 13. Inverter Heat Sink, Zig-Zag Transformer, And Output Filter (End View).

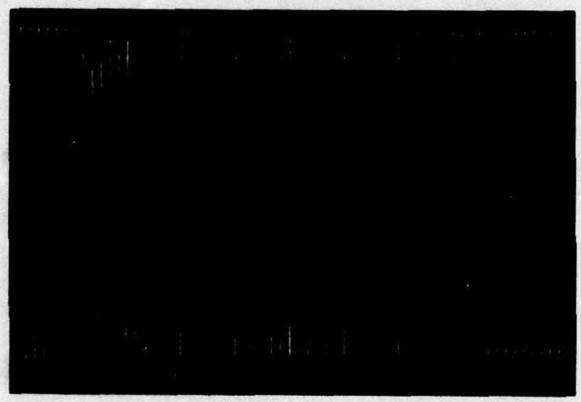


Figure 14. Transient Response Of The Turbo-Alternator Inverter System For A Step Change In Load From No Load To Full Load, With The Inverter Operating at 60 Hz. The Response Time Is Determined By The Time Constant Of The Alternator Field And The Droop Primarily By The Alternator Impedance.

## APPENDIX
## MERDC 10 KW BREADBOARD INVERTER - HIGH SPEED ALTERNATOR SYSTEM

### PERFORMANCE SUMMARY

Input: ±142 Vdc (rectified output of turbo-alternator unit)

Output: 120/208 Vrms, three-phase, 400 Hz or
120/208 Vrms, three-phase, 60 Hz
adjustable between 95 and 105 percent of rated voltage

Power Rating: 10 kW, 0.8 power factor (p.f.) lagging, 200% rated current for five seconds

Voltage Waveform: Total harmonic content
4.2% at 60 Hz
3.5% at 400 Hz

DC voltage component less than 10 mV.

Efficiency:

| Frequency (Hz) | Load (p.f.) | Efficiency(%) |
|---|---|---|
| 60 | 10 kW, 1.0 | 92.7 |
| 60 | 10 kW, 0.8 | 87.8 |
| 400 | 10 kW, 1.0 | 91.9 |
| 400 | 10 kW, 0.8 | 88.9 |

Phase Voltage Balance:

Unbalance is less than 0.5% for all balanced three-phase loads.

Phase Angle Balance:

The 120° angular difference between any two adjacent voltage vectors varies by less than 2° for all balanced load conditions and less than 5° for 25% single-phase, line-to-line loading.

Voltage Regulation:

Closed loop - less than 1-1/2% for all load conditions up to full load.

Open loop - (inverter) 4.5% at 10 kW

Effect of Unbalanced Load:

With the turbo-alternator inverter system operating at no load, rated voltage and frequency, application of a single-phase, line-to-line, unity p.f. load equal to 25% of rated current caused worst case line-t-line voltage differences of 6.9% at 60 Hz and 6.1% at 400 Hz.

Transient Voltage Performance:

(a) With the turbo-alternator inverter system initially operating at no load, rated voltage and rated frequency, the rms terminal voltage dropped to 70% of rated voltage when a 0.4 p.f. lagging load having an impedance of 0.5/unit was applied to the output terminals of the set. The system recovered to rated voltage in less than 200 msec.

(b) With the system operating at rated frequency and rated voltage, a step change in load from no load to rated load caused the output voltage to drop to 77% of rated voltage. The system recovered to rated voltage in less than 150 msec. When the load is suddenly changed from rated load to no load, the initial voltage transient is < 120% rated voltage.

Short Circuit Performance:

The inverter withstands short circuits for at least five seconds without damage. Output current is limited to 200% rated current by means of the alternator field control.

Frequency:

The inverter will produce power at either 60 Hz or 400 Hz. Frequency of the inverter is crystal-controlled and is independent of load or voltage changes.

# APPENDIX D

Item 0004

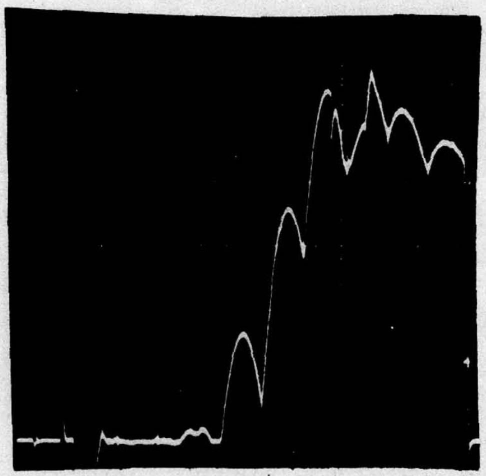
CDRL Item A0002

Modification P0006

Contract No. DAAK02-72-C-0210

| DELCO ELECTRONICS GENERAL MOTORS CORPORATION | REPORT NO. ITEM NO. 0002 | PAGE | JOB NO. APPENDIX D | PAGE 1 |
|---|---|---|---|---|
| TITLE 10KW FREQUENCY CONVERTER ITEMS 0001, 0003 AND 0004 CONTRACT NO. DAAK 02-73-C-0210. | | PREPARED CORRY | | DATE 2/21/74 |
| | | CHECKED | | |
| | | APPROVED | | |

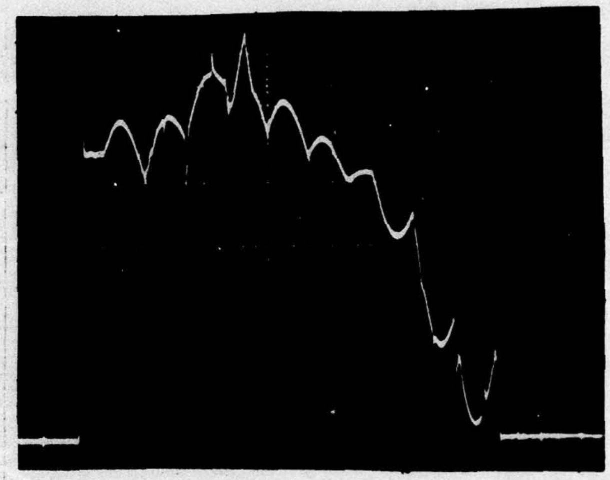
THYRISTOR, DIODE AND STEP TRANSFORMER CURRENTS FOR 1PU AND 2PU OPERATION. (FREQUENCY CONVERTER OPERATING AT 400 HZ, THREE PHASE, FREE COMMUTATION STEPS, POWER FACTOR CORRECTED WITH 50 MFD L-T-L)



- TOTAL RIGHT SIDE STEP CURRENTS
- PHASE SELECTOR CURRENT

↕ 10A/DIV. ↔ 100μSEC/DIV.

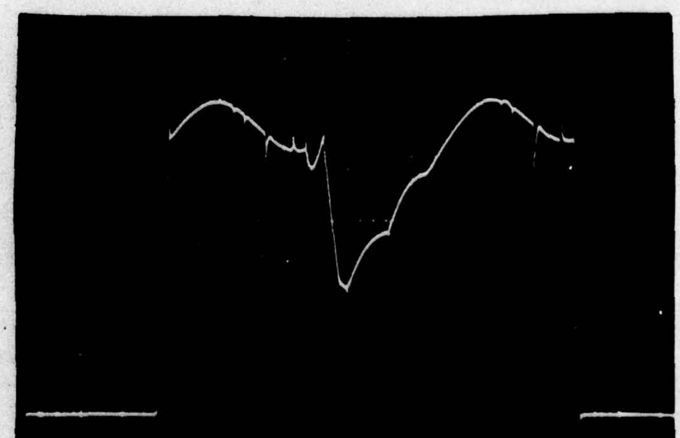
1 P.U.



POWER CENTER CURRENT $P_A^-$

↕ 10A/DIV. 100μSEC/DIV.

1 P.U. LOAD 11KW, PF = 0.8



POWER CENTER CURRENT $P_A^-$

↕ 20A/DIV. 100μSEC/DIV.

2 P.U. LOAD 22KW, PF = 0.8

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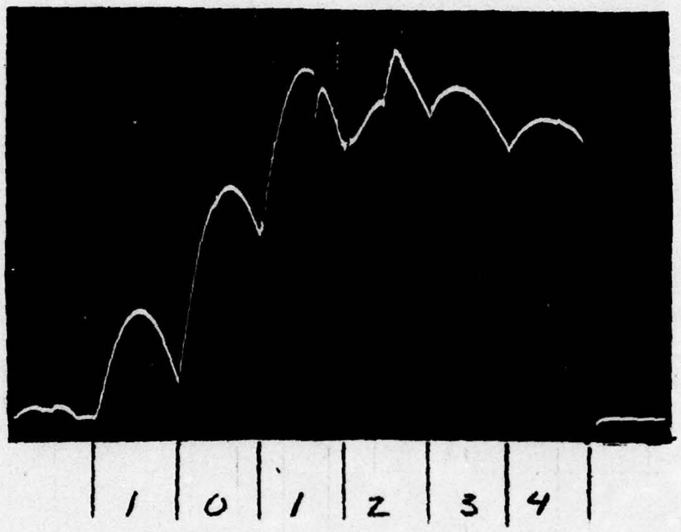
RIGHT SIDE STEP CURRENTS & RT. PHASE SELECTOR CURRENT

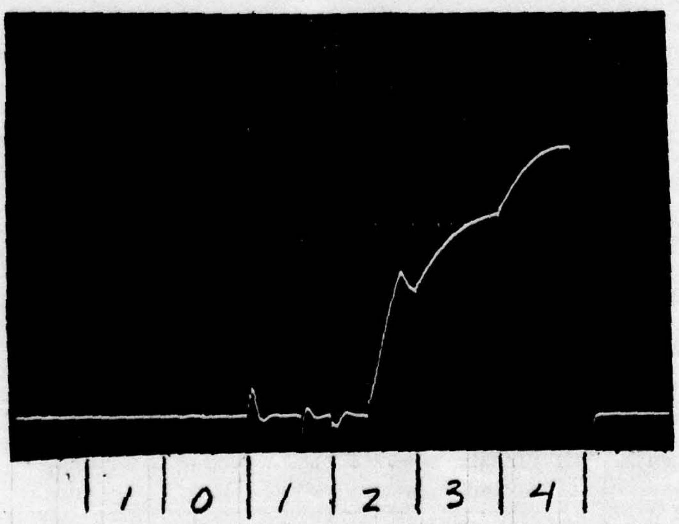



STEP NUMBER

1 P.U. LOAD

↕ 10A/DIV.

↔ 50 μSEC/DIV.




2 P.U. LOAD

↕ 20A/DIV.

↔ 50 μSEC/DIV.

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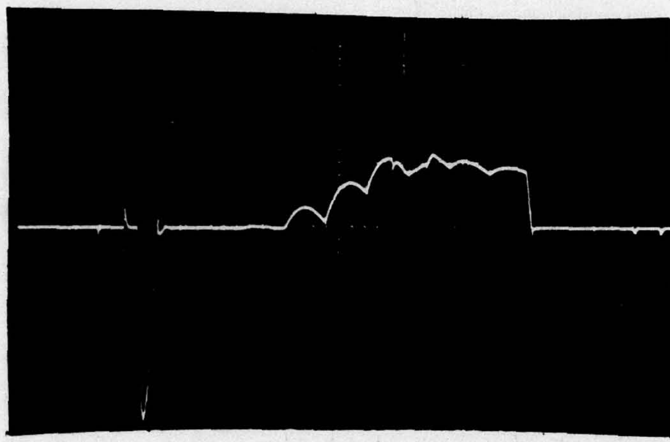
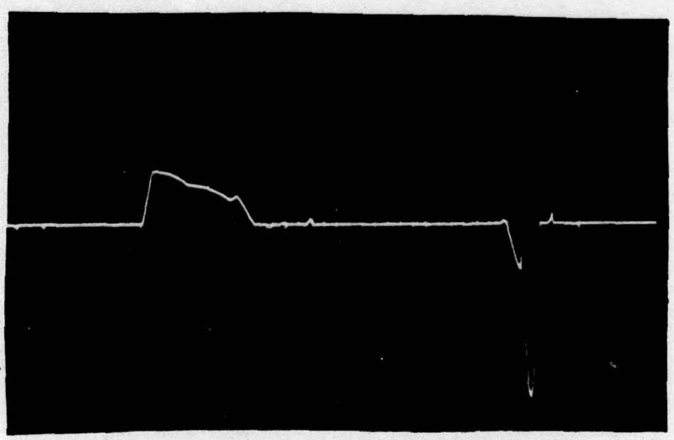


+ RIGHT SIDE PHASE SELECTOR CURRENT

+ − R5 & PHASE SELECTOR COMMUTATION CURRENT

1 P.U. LOAD

↕ 50 A/DIV. ↔ 100 μSEC/DIV.



2 P.U. LOAD

↕ 100A/DIV ↔ 100 μSEC/DIV.

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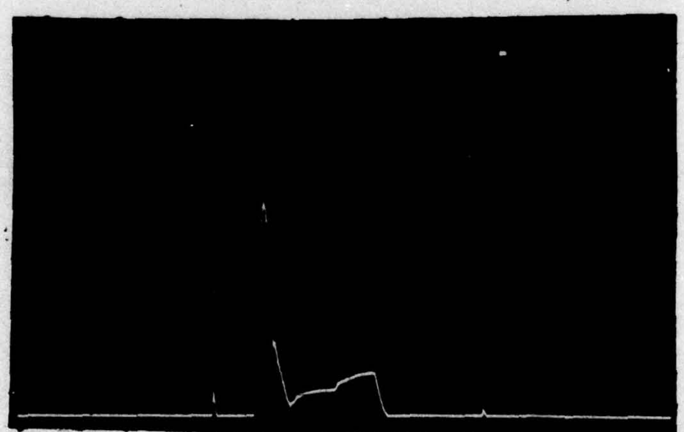
T- CURRENT

1 P.U. LOAD

↕ 50A/DIV.

↔ 100 $\mu$SEC/DIV.

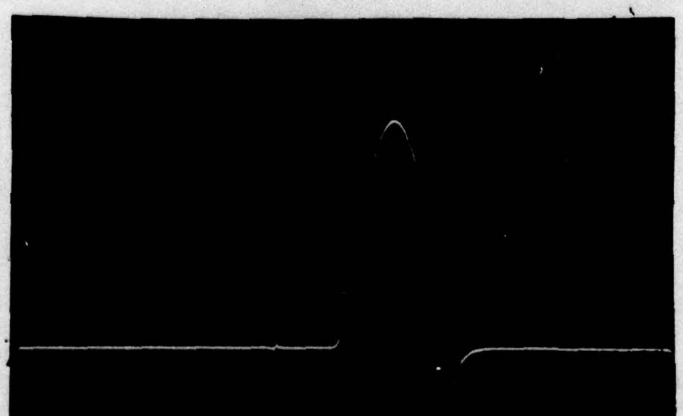


2 P.U. LOAD

↕ 100A/DIV.

↔ 100 $\mu$SEC/DIV.

$T_c$ - CURRENT



↕ 20A/DIV.

↔ 10 $\mu$SEC/DIV.

SAME MAGNITUDE FOR 1 P.U. OR 2 P.U. LOADS

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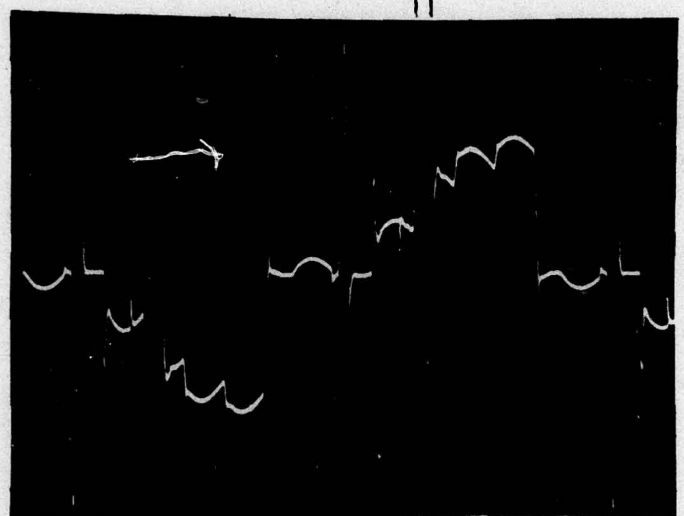
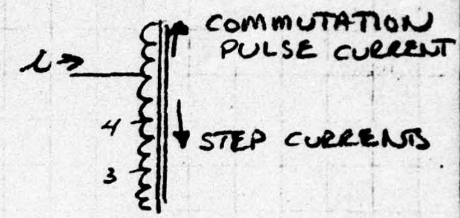
|---|---|---|
| | CHECKED | |
| | APPROVED | |

# STEP TRANSFORMER CURRENT

200 AMPS. PEAK
POLLAR CENTRAL
COMMUTATION
CURRENT

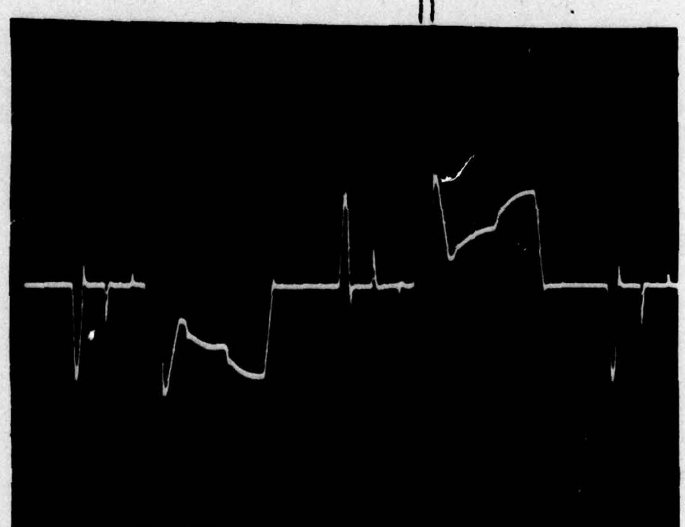





1 P.U. LOAD

↕ 20A / DIV.
↔ 100 μSEC / DIV.

320 AMPS. PEAK
COMMUTATION
CURRENT



2 P.U. LOAD

↕ 50 A / DIV.
↔ 100 μSEC / DIV.

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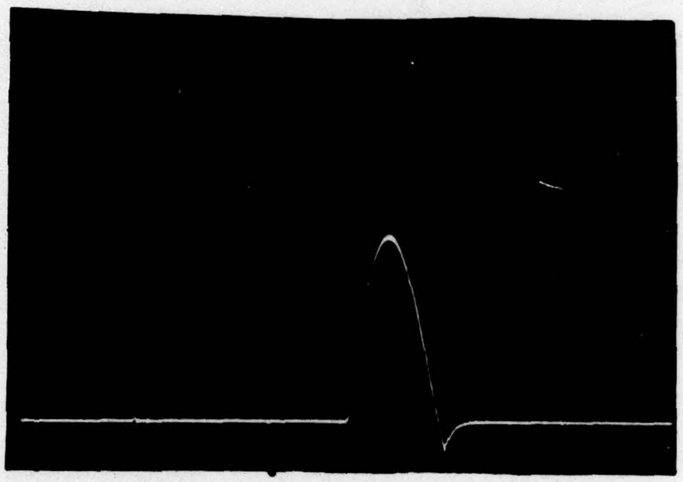
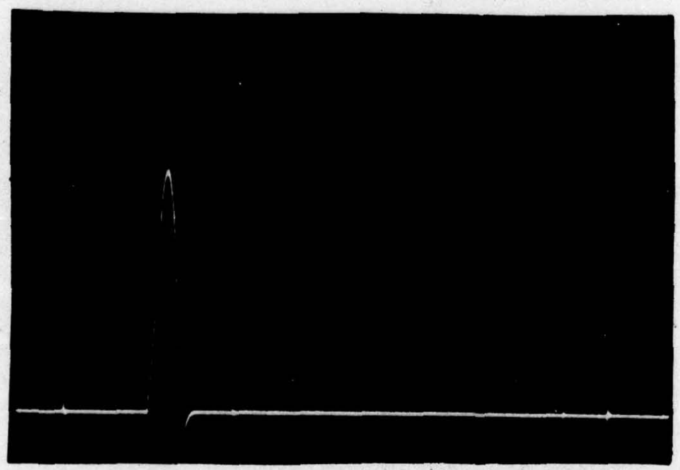
POWER CENTER BY-PASS DIODE CURRENT



1 P.U. LOAD

↕ 50A/DIV.

↔ 20 μSEC/DIV.



2 P.U. LOAD

↕ 50 A/DIV.

↔ 50 μSEC/DIV.

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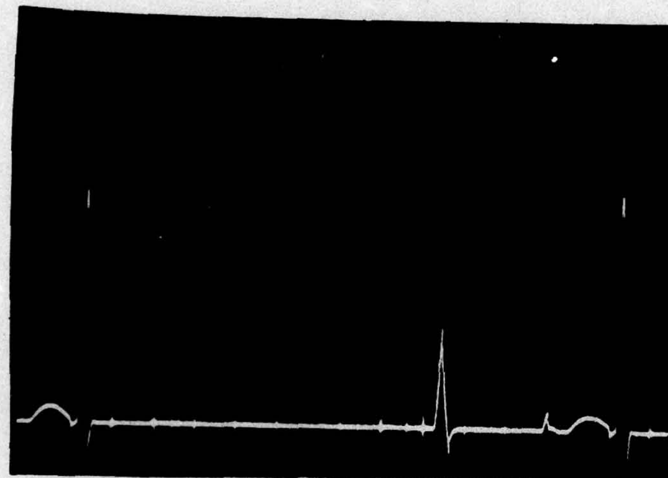
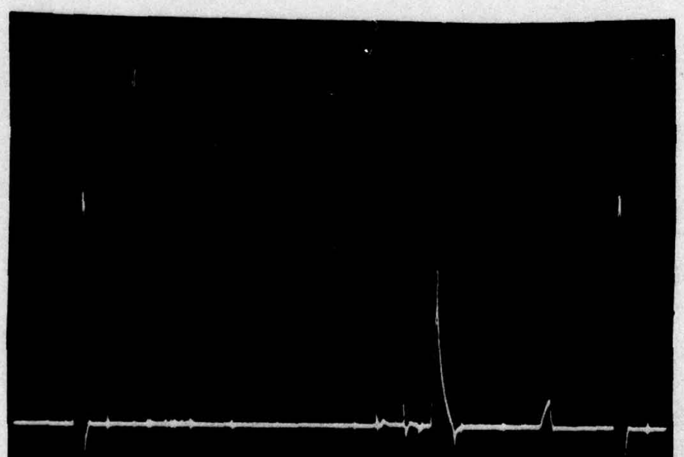
T- BY-PASS DIODE CURRENT



1 P.U. LOAD

↕ 20A/DIV.

↔ 100 μSEC/DIV.



2 P.U. LOAD

↕ 20A/DIV.

↔ 100 μSEC/DIV.

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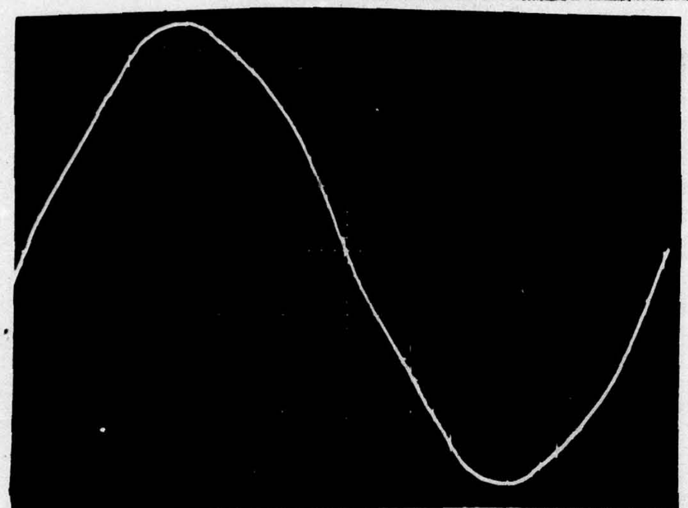
FREQUENCY CONVERTER OUTPUT VOLTAGE FOR PRECEDING CURRENT MEASUREMENTS



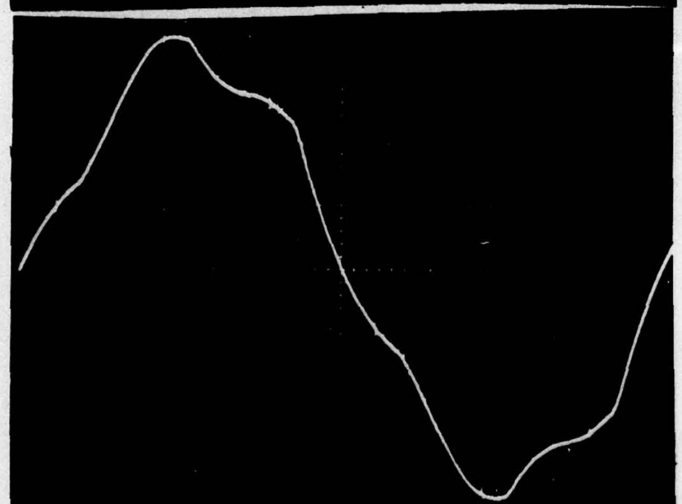
L-T-N VOLTAGE

1 P.U. LOAD

THD = 2.76%

$V_{DC}$ = 295 VDC.

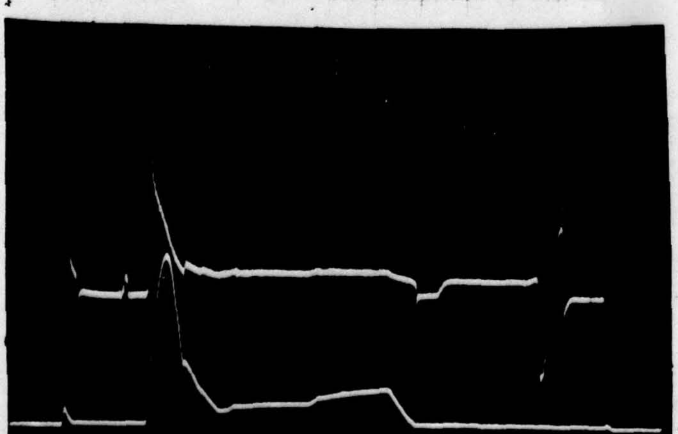
(THREE WIRE INPUT)



2 P.U. LOAD

THD = 8.8%

$V_{DC}$ = 307 VDC.



T - VOLTAGE DROP & CURRENT MAGNITUDE

VOLTAGE ↕ 5V/DIV.

⟷ 50 μSEC/DIV.

CURRENT 100A/DIV

DISTRIBUTION:

10 KW FREQUENCY CONVERTER

Test Results Item 0001

CDRL Item A002

Contract No. DAAK02-72-C-0210

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

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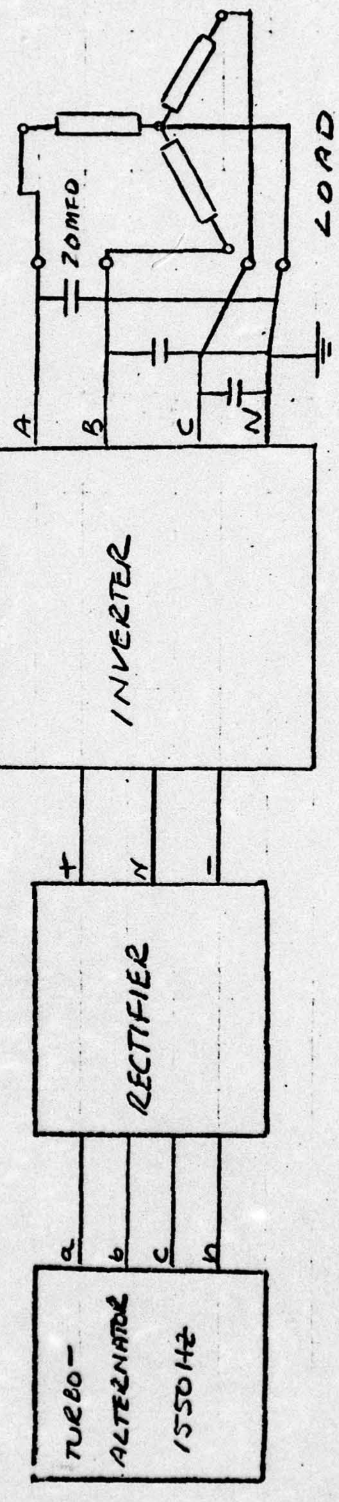


CONNECTIONS FOR 400HZ OR 60HZ THREE PHASE POWER

FOR DATA ON PAGES 1-14

DISTRIBUTION:

DE-255 REV. 12-66

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO. ITEM 0002 | PAGE | JOB NO. | PAGE 1

TITLE 10KW FREQUENCY CONVERTER ITEM 0001 CONTRACT NO. DAAK 02-72-C-0210 TEST DATA

PREPARED BARRETT | DATE 1/31/73
CHECKED
APPROVED

TESTS IN ACCORDANCE WITH ATTACHMENT NO. 1 AND MIL-STD-705 B

3.24.1.1 Voltage Operating Range #

| | VOLTS RMS MIN. | VOLTS RMS MAX. |
|---|---|---|
| 400HZ NO LOAD | 110.1 | 133.3 |
| 60HZ NO LOAD | 111.7 | 135.0 |
| 400HZ 10KW PF=1.0 | <114.0 | 122.7 * |
| 60HZ 10KW PF=1.0 | <114.0 | 123.3* |
| 400HZ 10KW 0.8PF | <114.0 | 119.7 * * |
| 60HZ 10KW 0.8PF | <114.0 | 120.4* * |

* $I_{real} = 25.9$ A.

* * $I_{real} = 25.9$ A.

$I_{reac.} = 19.4$ A.

\# ALTERNATOR FIELD CONTROL CIRCUIT NOT INCLUDED IN CONTRACT WORK STATEMENT

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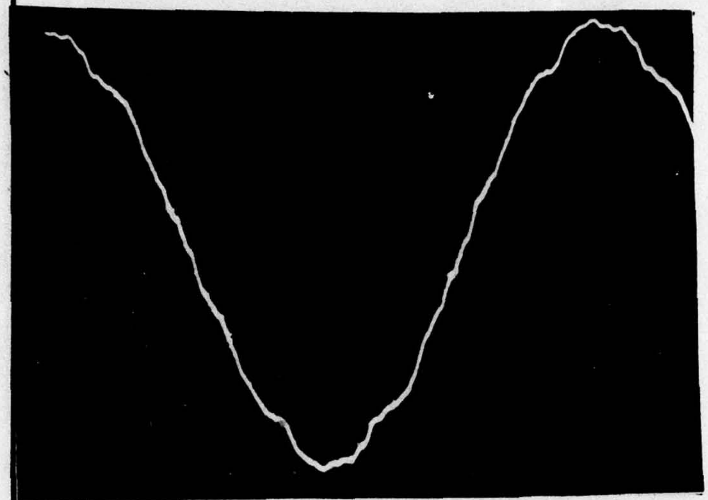
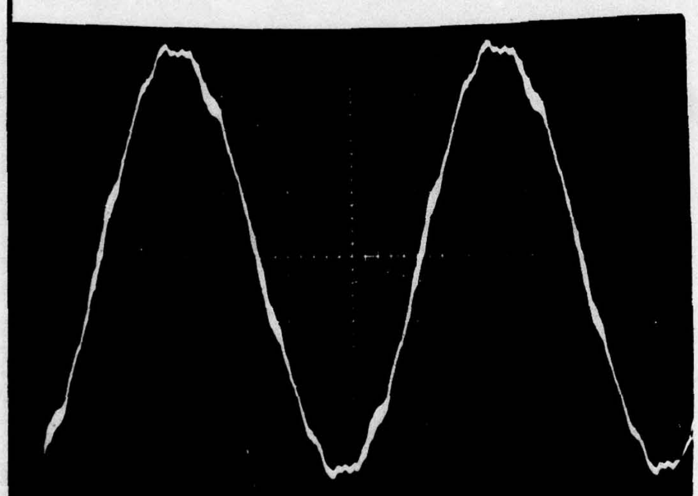
3.24.1.3 VOLTAGE WAVEFORM



400 HZ THREE PHASE LINE-TO-NEUTRAL VOLTAGES

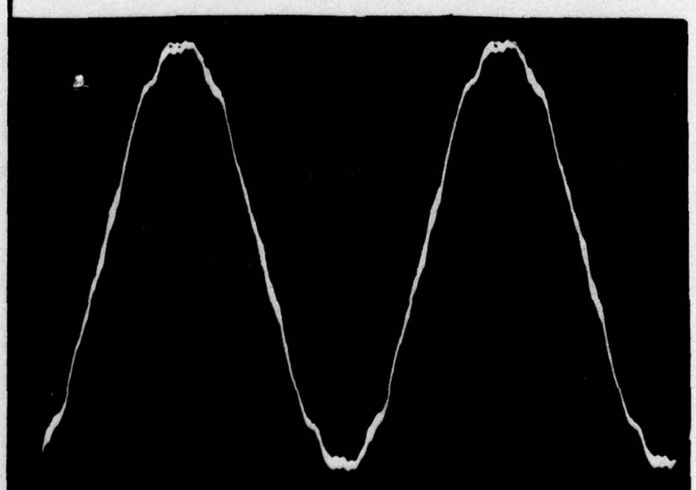
NO LOAD

THD=3.4%



11KW, PF=1.0

THD= 3.1%



11KW, PF= 0.8

THD= 3.1%

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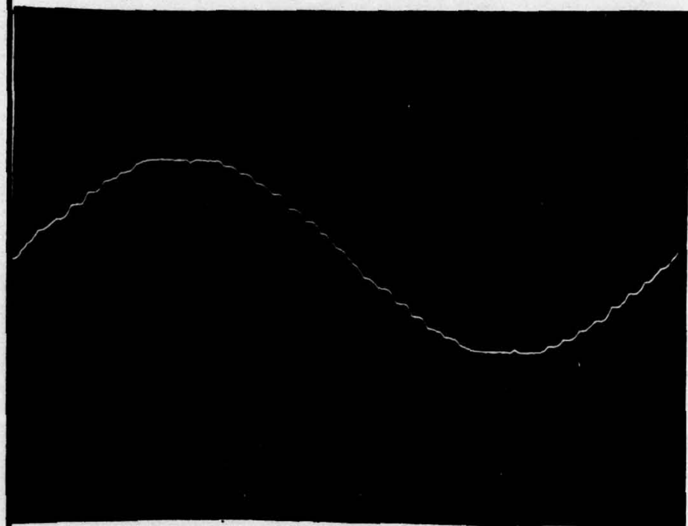
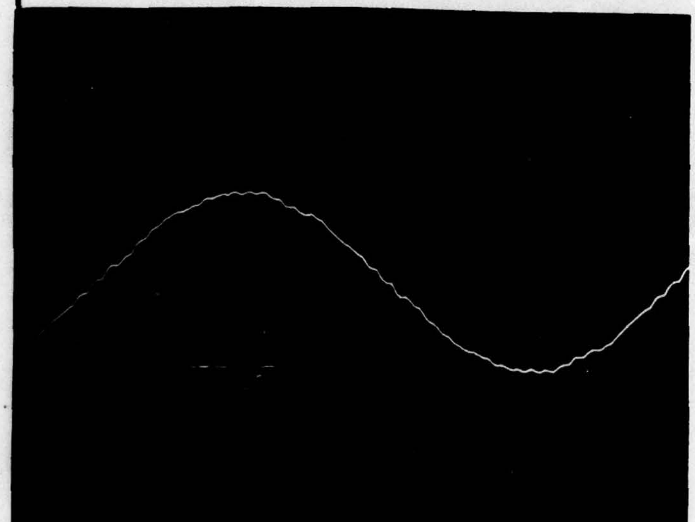


400 HZ THREE PHASE LINE-TO-LINE VOLTAGES

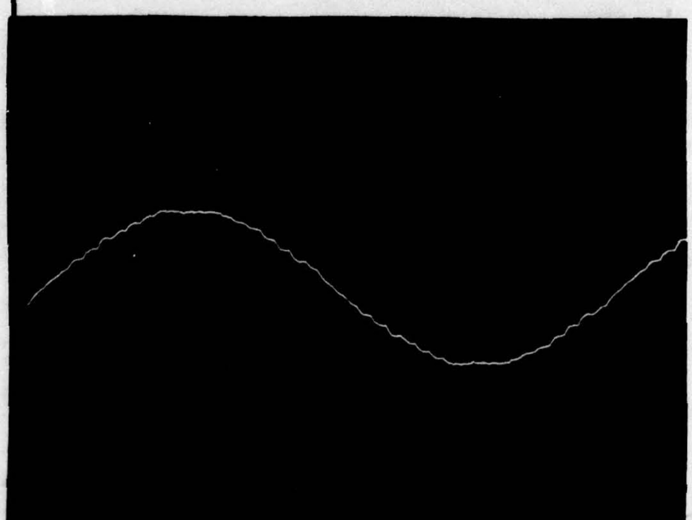
NO LOAD

THD= 3.3%



11 KW, PF=1.0

THD=3.1%



11 KW, PF= 0.8

THD=3.1%

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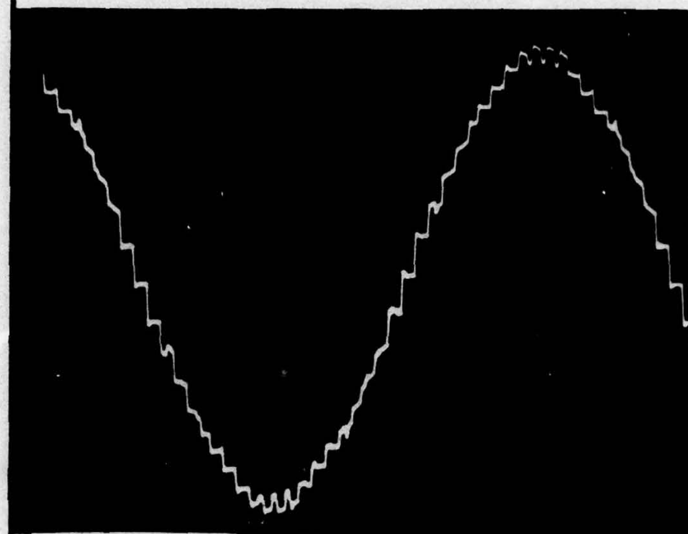
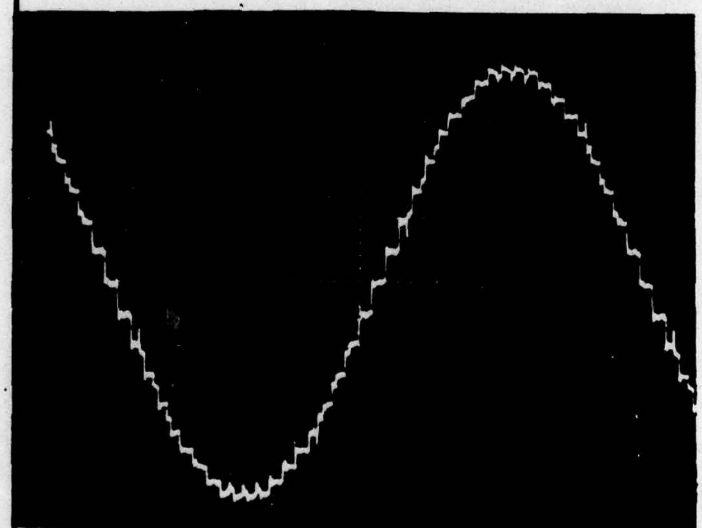
60 HZ THREE PHASE
LINE-TO-NEUTRAL
VOLTAGES



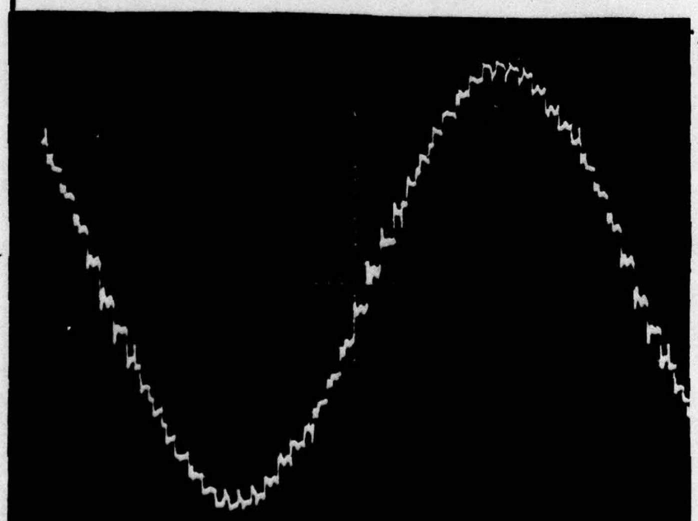
NO LOAD

THD= 3.83%



11KW, PF=1.0

THD= 4.0%



11KW, PF=0.8

THD=4.6%

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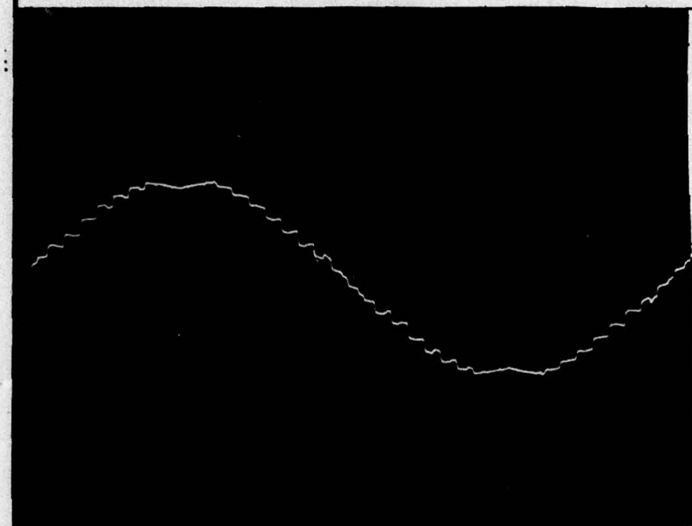

60HZ THREE PHASE
LINE-TO-LINE
VOLTAGE

NO LOAD

THD= 3.81%

4.6.1 DC CONTENT TEST

THE DC VOLTAGE LEVEL AT THE OUTPUT TERMINALS AT RATED LOAD, 0.8 PF, 1.0PF AND NO LOAD AT 60HZ AND 400HZ IS LESS THAN 50 MILLIVOLTS FOR ALL VOLTAGE CONNECTIONS.

3.24.1.4 PHASE VOLTAGE BALANCE

| | 60HZ | 400HZ |
|---|---|---|
| Van | 119.6 Vrms | 120.0 Vrms |
| Vb-n | 119.3 " | 120.1 " |
| Vc-n | 119.1 " | 120.2 " |
| Va-b | 206.4 " | 207.4 " |
| Vb-c | 206.1 " | 208.4 " |
| Vc-a | 206.2 " | 207.6 " |

CONDITIONS: NO LOAD

ALL VOLTAGES WITHIN 1% OF RATED VOLTAGE

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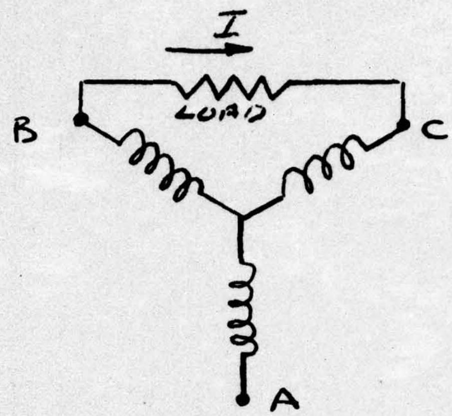
3.24.1.5 EFFECT OF UNBALANCED LOAD (3PHASE)




I = 8.5 Arms

| | 60HZ | 400HZ |
|---|---|---|
| $V_{BC}$ | 207.8 | 208.0 |
| $V_{BA}$ | 221.0 | 217.4 |
| $V_{AC}$ | 222.1 | 220.7 |
| $V_{CN}$ | 122.9 | 123.1 |
| $V_{BN}$ | 122.3 | 121.2 |
| $V_{AN}$ | 130.2 | 128.2 |

| | 60HZ UNBALANCE | 400 HZ UNBALANCE |
|---|---|---|
| L-L | 6.9% | 6.1% |
| L-N | 6.6% | 5.8% |

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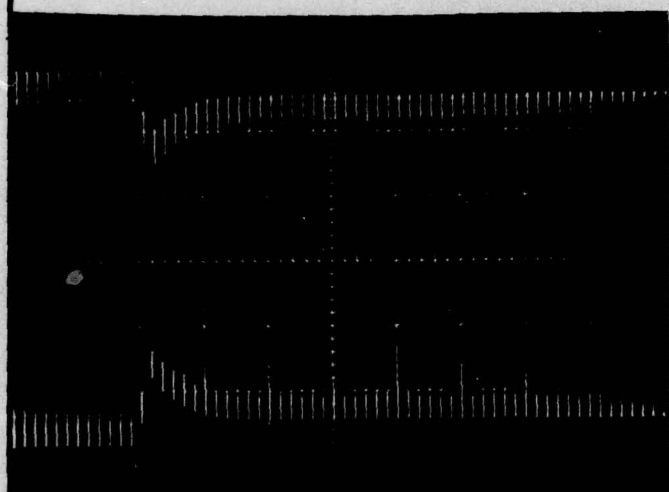
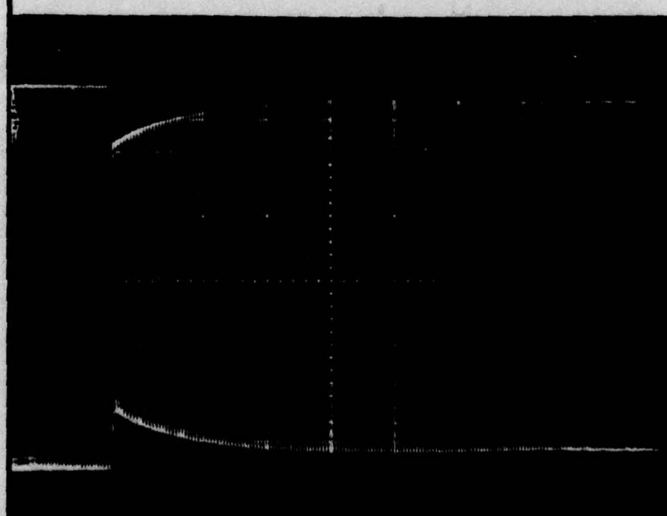
3.24.1.12 TRANSIENT VOLTAGE PERFORMANCE

a) APPLICATION OF 0.4 PF, 0.5 PER UNIT IMPEDANCE LOAD



60 HZ

HOR. SCALE 100ms/DIV.



400 HZ

HOR. SCALE 50ms/DIV.

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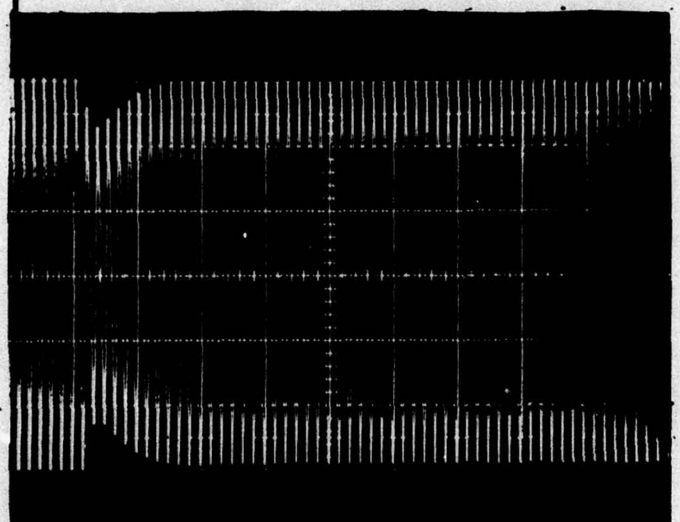
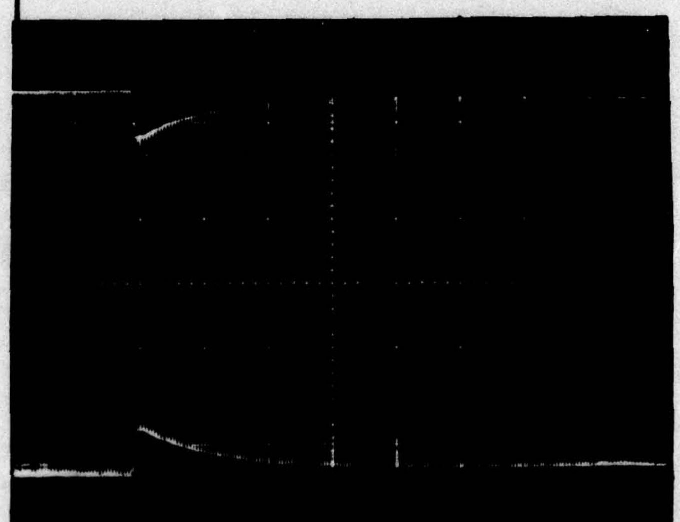
b) APPLICATION OF 11KW, 0.8PF. LOAD



60 HZ

HOR. SCALE 100 mv/DIV.



400 HZ

HOR. SCALE 50 mv/DIV.

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3.24.1.13 SHORT CIRCUIT TS12.1C MODIFIED

THE OUTPUT BREAKER ON THE FREQUENCY CONVERTER WAS OPENED AND CLOSED - NO LOAD TO SHORT CIRCUIT. THE SHORT CIRCUIT CURRENT WAS OBSERVED ON A SCOPE AND THE MAGNITUDE WAS READ FROM A CURRENT TRANSFORMER ON A HP3400 TRUE RMS VOLTMETER.

AT 60HZ THE SHORT CIRCUIT CURRENT WAS 65A. RMS.

AT 400HZ THE SHORT CIRCUIT CURRENT WAS 72A. RMS.

---

3.24.3 EFFICIENCY

SUMMATION OF LOSSES ON MERDC 10KW FREQUENCY CONVERTER

1) INPUT POWER WAS MEASURED AFTER THE INPUT FILTER CAPACITORS. AVERAGE RESPONDING INSTRUMENTS WERE USED.

a) INPUT VOLTAGES FROM +LINE TO -LINE WERE MEASURED WITH A HP3440A DVM. IT WAS CHECKED AGAINST A HP3450A DVM AND A WESTON 622 THERMOCOUPLE VOLTMETER.

b) INPUT CURRENT WAS MEASURED WITH A HP3440A AND A T&M COAXIAL CURRENT VIEWING RESISTOR (CVR). THE READINGS WERE CHECKED WITH A WESTON 931 AND A 100A. SHUNT.

2) OUTPUT POWER WAS MEASURED AT THE FREQUENCY CONVERTER OUTPUT TERMINALS. TRUE RMS INSTRUMENTS

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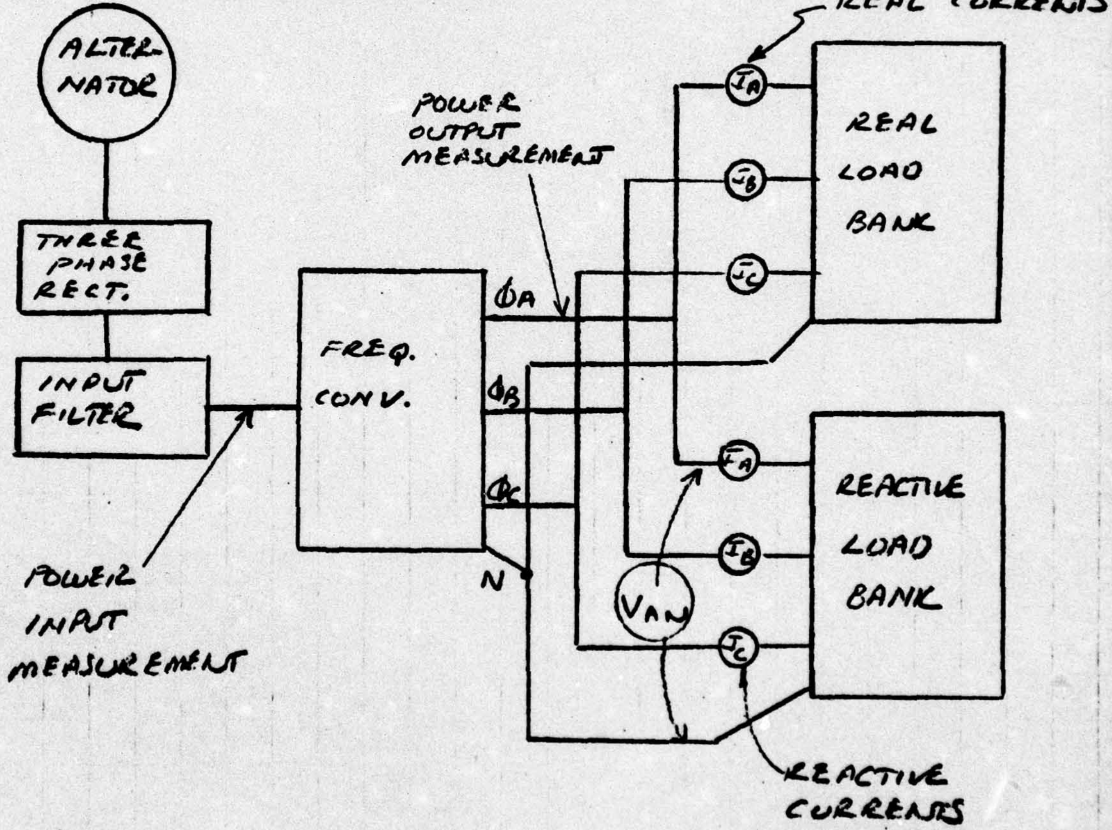
WERE USED.

a) LINE TO NEUTRAL OUTPUT VOLTAGES ON ALL THREE PHASES WERE MEASURED WITH A HP3450A THAT WAS CHECKED AGAINST A WESTON 622.

b) OUTPUT CURRENT ON ALL THREE PHASES WAS MEASURED WITH A HP3450A AND PEARSON 110 CURRENT TRANSFORMERS. OUTPUT POWER ON PHASE A WAS CHECKED WITH A WESTON 432 WATTMETER.




3) EFFICIENCY ($\eta$) IS CALCULATED FROM DATA TAKEN WITH THE AFOREMENTIONED DIGITAL EQUIPMENT AND SHUNTS. FOR COMPARATIVE PURPOSES DATA TAKEN WITH CONVENTIONAL MOVING COIL METERS IS PRESENTED.

4) CALCULATED EFFICIENCY AT 0.8 PF IS PROBABLY SLIGHTLY ON THE LOW SIDE (LESS THAN 1%) BECAUSE

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IT WAS ASSUMED THAT THERE ARE NO POWER LOSSES IN THE REACTIVE LOAD BANK. THE REAL LOAD BANK IS ESSENTIALLY PURELY RESISTIVE.

5) TABULATION OF FIXED LOSSES —

| | | |
|---|---|---|
| a) TRIGGER CIRCUITS | 30 VOLTS x 3.3 AMPS | = 99 WATTS. |
| b) INPUT INDUCTOR | | = 15 " |
| c) INPUT CAPACITORS | | = 20 " |
| d) INPUT RECTIFIERS | | = 100 " |
| | | 234 WATTS. |

FREQUENCY 60HZ    LOAD 10KW 1.0PF

| | TRIAL ① | TRIAL ② | AVG. | |
|---|---|---|---|---|
| 1. DC INPUT VOLTAGE | 298.0 | 296.5 | 297.3 | VOLTS DC |
| 2. DC INPUT CURRENT | 36.1 | 35.9 | 36.0 | AMPS DC |
| 3. $\phi A$ OUTPUT VOLTAGE | 120.38 | 119.49 | 119.94 | V RMS |
| 4. $\phi_B$ " " | 121.14 | 120.30 | 120.72 | " " |
| 5. $\phi_C$ " " | 120.90 | 120.36 | 120.63 | " " |
| 6. $\phi_A$ OUTPUT CURRENT | 28.43 | 28.25 | 28.34 | A. RMS |
| 7. $\phi_B$ " " | 27.98 | 27.81 | 27.89 | " " |
| 8. $\phi_C$ " " | 28.03 | 27.87 | 27.95 | " " |

POWER INPUT (297.3 VOLTS)(36.0 AMPS) = 10,703 WATTS.
FIXED LOSSES 234 "

POWER OUTPUT (120.72)(27.89) = 3367 WATTS
(119.94)(28.34) = 3399 "
(120.63)(27.95) = 3372 "
10,138 WATTS

$$\eta = \frac{(10138)(100)}{(10703)+(234)} = 92.7\%$$

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FREQUENCY 400 HZ LOAD 10KW 1.0PF

| | TRIAL ① | TRIAL ② | AVG. |
|---|---|---|---|
| 1. DC INPUT VOLTAGE | 299.1 | 297.8 | 298.5 |
| 2. DC INPUT CURRENT | 36.5 | 36.5 | 36.5 |
| 3. $\phi_A$ OUTPUT VOLTAGE | 119.88 | 118.87 | 119.38 |
| 4. $\phi_B$ " " | 122.00 | 121.23 | 121.61 |
| 5. $\phi_C$ " " | 122.22 | 121.59 | 121.90 |
| 6. $\phi_A$ OUTPUT CURRENT | 28.33 | 28.15 | 28.24 |
| 7. $\phi_B$ " " | 28.23 | 28.06 | 28.15 |
| 8. $\phi_C$ " " | 28.29 | 28.13 | 28.21 |

POWER INPUT (298.5)(36.5) = 10895 WATTS.
FIXED LOSSES 234 "

POWER OUTPUT (119.38)(28.24) = 3371 WATTS
(121.61)(28.15) = 3423 "
(121.90)(28.21) = 3439 "
10233 WATTS

$$\eta = \frac{(10233)(100)}{(10895) + (234)} = \underline{\underline{91.9\%}}$$

FREQUENCY 60HZ LOAD 10KW 0.8PF

| | TRIAL ① | TRIAL ② | AVG. |
|---|---|---|---|
| 1. DC INPUT VOLTAGE | 302.3 | 298.4 | 300.4 |
| 2. DC INPUT CURRENT | 38.7 | 38.2 | 38.5 |
| 3. $\phi_A$ OUTPUT VOLTAGE | 122.07 | 120.48 | 121.27 |
| 4. $\phi_B$ " " | 122.77 | 121.45 | 121.11 |
| 5. $\phi_C$ " " | 122.52 | 121.32 | 121.92 |
| 6. $\phi_A$ REAL OUTPUT CURRENT | 28.82 | 28.68 | 28.75 |
| 7. $\phi_B$ " " " | 28.36 | 28.24 | 28.30 |
| 8. $\phi_C$ " " " | 28.31 | 28.22 | 28.26 |
| 9. $\phi_A$ REACTIVE OUTPUT CURRENT | 20.8 | | |
| 10. $\phi_B$ " " " | 20.8 | | |
| 11. $\phi_C$ " " " | 20.8 | | |

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POWER INPUT (300.4)(38.5) = 11,565 WATTS
FIXED LOSSES 234 "

POWER OUTPUT (121.27)(28.75) = 3487 WATTS.
(121.11)(28.30) = 3427 "
(121.92)(28.26) = 3445 "
10359 WATTS.

K-VAR (APPROX) (121.27)(20.8) = 2522 VAR
(121.11)(20.8) = 2519 "
(121.92)(20.8) = 2536 "
7,565 VAR

$$\eta = \frac{(10359)(100)}{(11565)+(234)} = \underline{\underline{87.8\%}}$$

---

FREQUENCY 400 HZ LOAD 10KW 0.8 PF

| | AVG. |
|---|---|
| 1. DC INPUT VOLTAGE | 299.0 |
| 2. DC INPUT CURRENT | 36.8 |
| 3. $\phi_A$ OUTPUT VOLTAGE | 118.08 |
| 4. $\phi_B$ " " | 120.92 |
| 5. $\phi_C$ " " | 119.80 |
| 6. $\phi_A$ REAL OUTPUT CURRENT | 27.90 |
| 7. $\phi_B$ " " " | 27.95 |
| 8. $\phi_C$ " " " | 27.72 |
| 9. $\phi_A$ REACTIVE OUTPUT CURRENT | 20.6 |
| 10. $\phi_B$ " " " | 20.6 |
| 11. $\phi_C$ " " " | 20.6 |

POWER INPUT (299.0)(36.8) = 11,003 WATTS
FIXED LOSSES 234 WATTS.
POWER OUTPUT (118.08)(27.90) = 3294 WATTS
(120.92)(27.95) = 3380 "
(119.8)(27.72) = 3321 "
9,995 WATTS

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KVAR (APPROX) (118.08)(20.6) = 2432 VAR
(120.92)(20.6) = 2491 "
(119.8)(20.6) = 2468 "
7391 VAR

$$\eta = \frac{(9995)(100)}{(11003)+234} = \underline{\underline{88.9\%}}$$

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10 KW FREQUENCY CONVERTER

Test Results Items 0001, 0003, 0004

Single Phase Performance

CDRL Item A002

Modification Nos. P0003 & P0006

Contract No. DAAK02-72-C-0210

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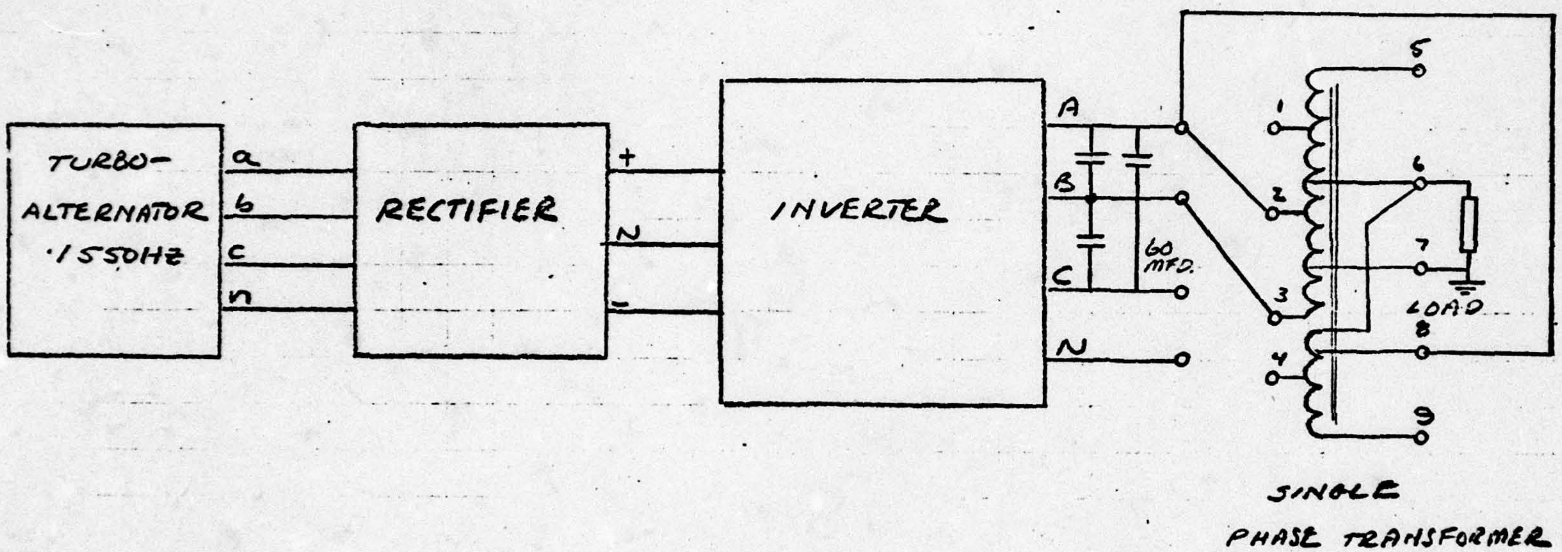


CONNECTIONS FOR 400HZ, SINGLE PHASE, TWO-WIRE POWER

(STEP TRANSISTORS NOT CONNECTED)

FOR DATA ON PAGES 15-37

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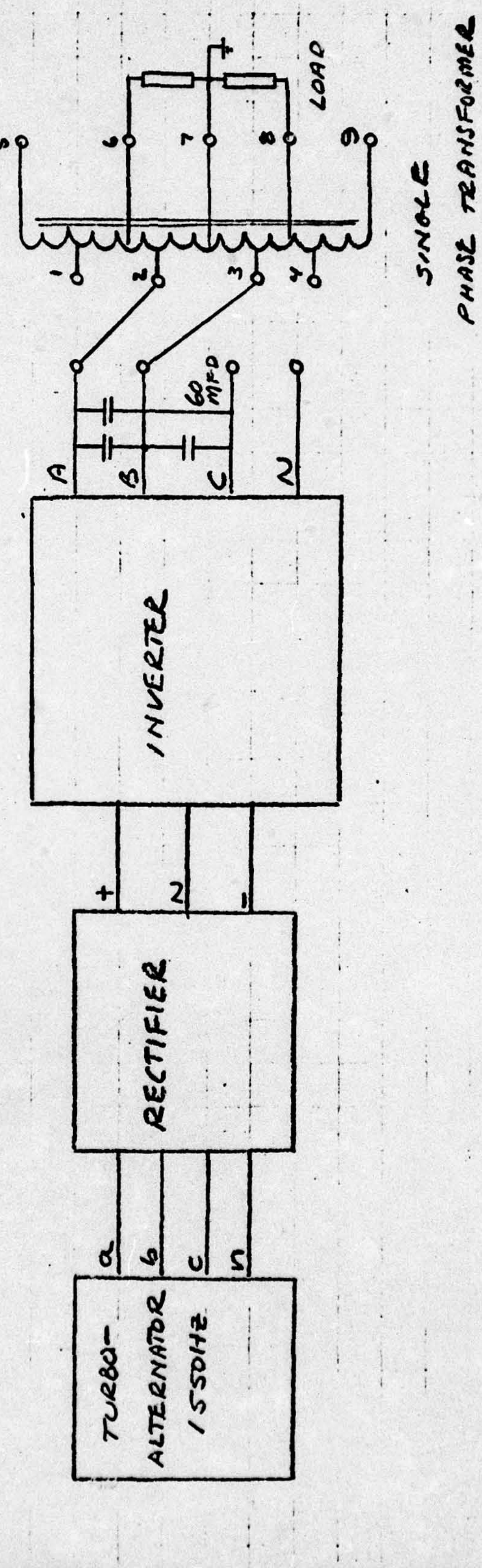


CONNECTIONS FOR 400HZ, SINGLE PHASE, THREE WIRE POWER

(STEP TRANSISTORS NOT CONNECTED)

FOR DATA ON PAGES 15-37

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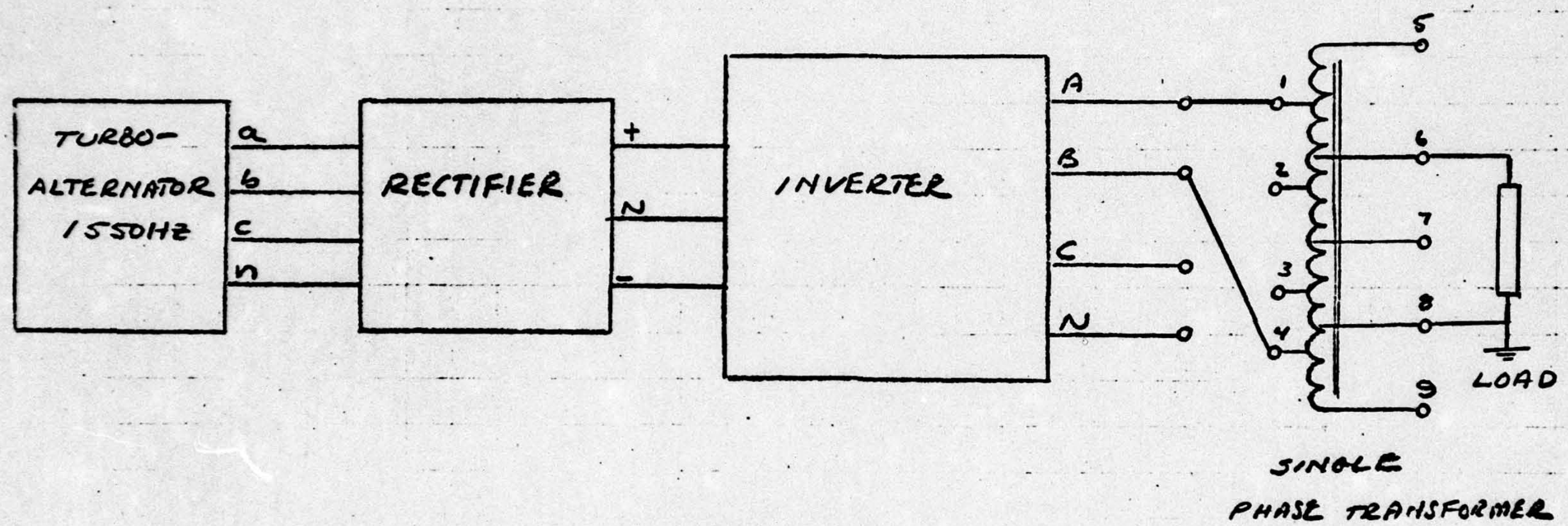


CONNECTIONS FOR 60HZ, SINGLE PHASE, TWO WIRE POWER

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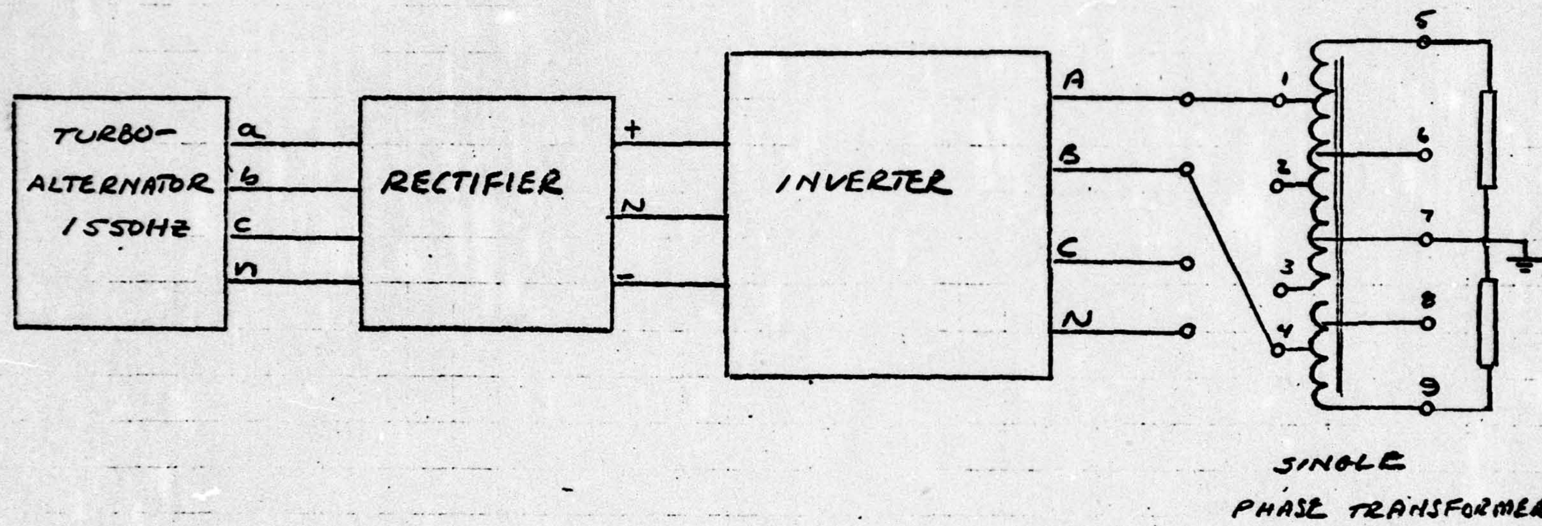


CONNECTIONS FOR 60HZ, SINGLE PHASE, THREE WIRE POWER

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| TITLE TESTS IN ACCORDANCE WITH ATTACHMENT NO.3 OF CONTRACT NO. DAAK02-72-C-0210 MODIFICATION NOS. P0003 & P0006 AND MIL-STD-705B. ITEMS 0001, 0003, 0004. | | PREPARED CORRY | | DATE 12/3/73 |
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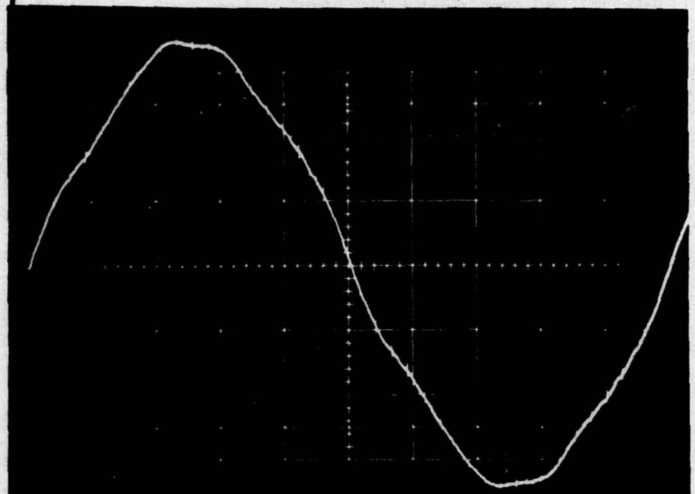
3.24.1.3 VOLTAGE WAVEFORM

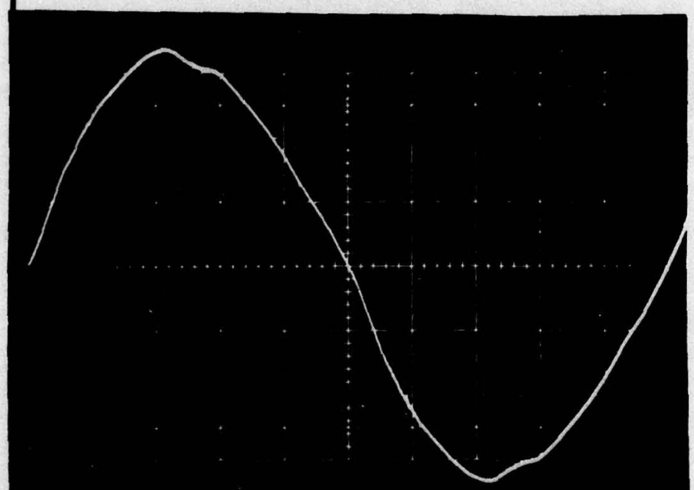


400 HZ SINGLE PHASE, TWO WIRE

NO LOAD

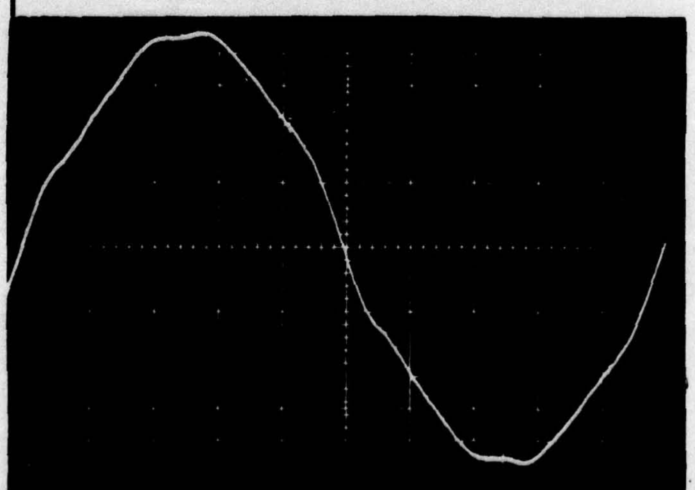
THD = 3.6%

50V/DIV.



10 KW, PF = 0.8

THD = 4.95%



10 KW, PF = 1.0

THD = 4.65%

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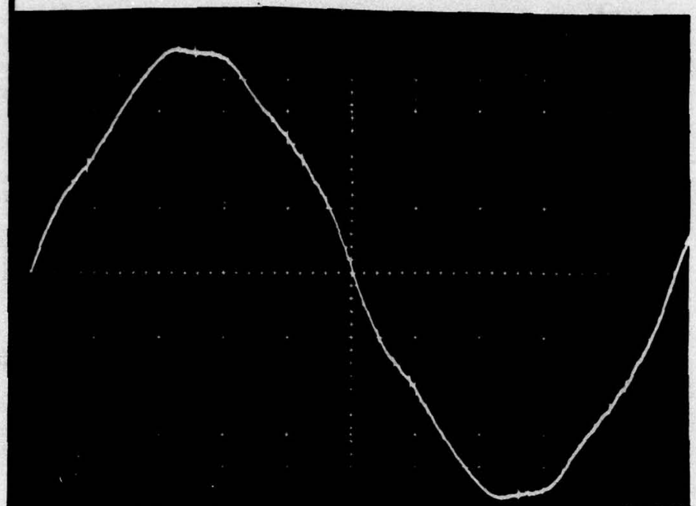
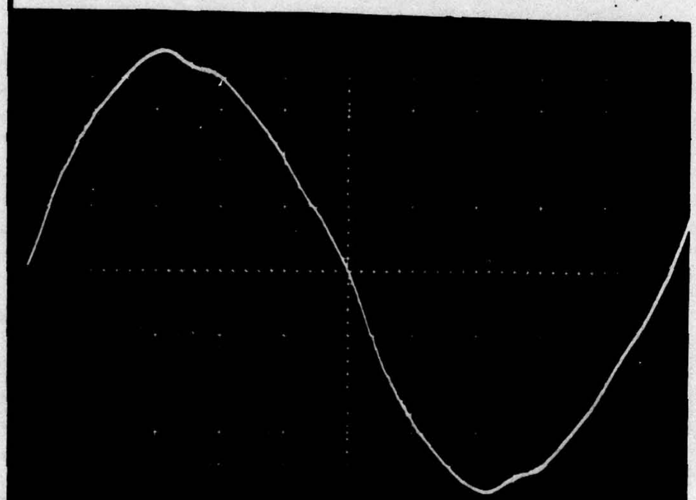


400 HZ SINGLE PHASE, THREE WIRE

NO LOAD

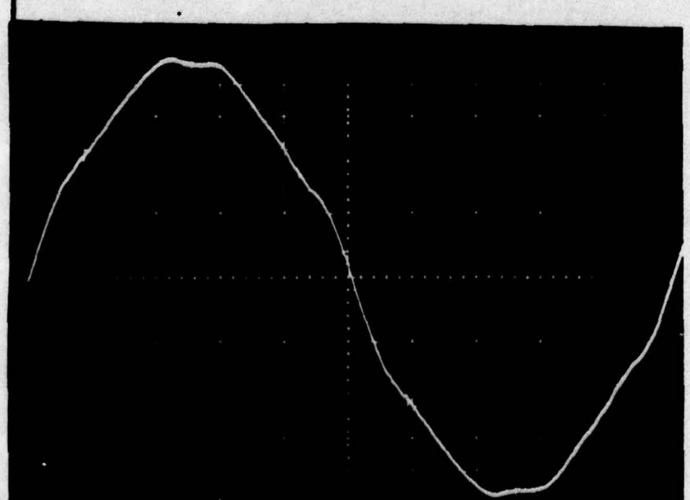
THD = 3.67%

50V / DIV.



10KW, PF = 0.8

THD = 5%



10KW, PF = 1.0

THD = 4.57%

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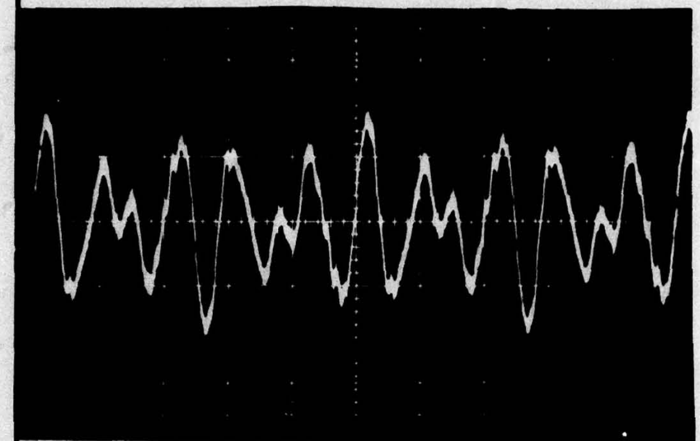
DEVIATION FACTOR

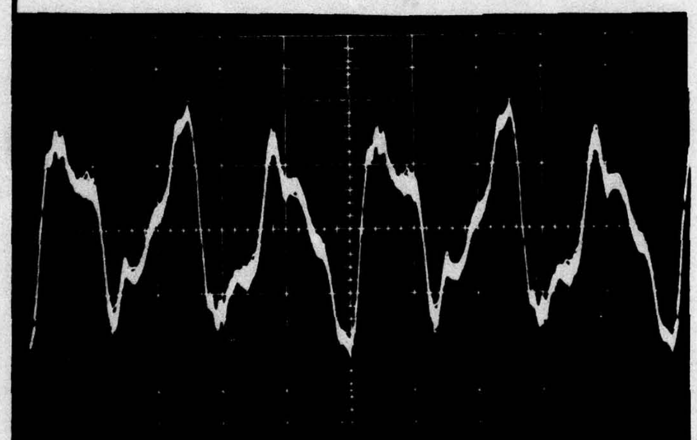


400 HZ SINGLE PHASE, TWO WIRE

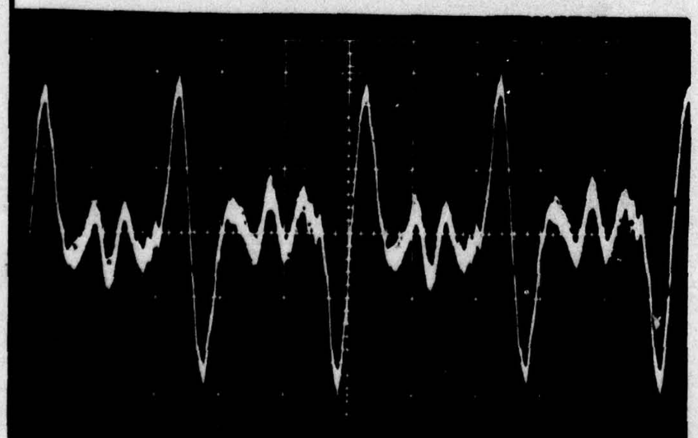
NO LOAD

↕ 0.5V/DIV.

↔ 500 μSEC/DIV.



10KW, PF=0.8



10KW, PF=1.0

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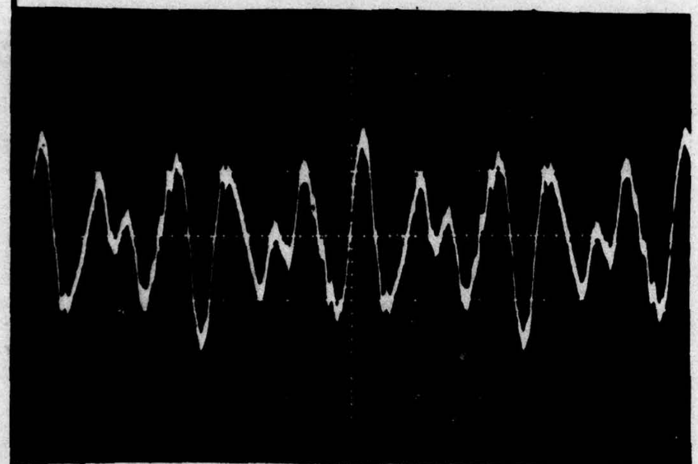
DEVIATION FACTOR

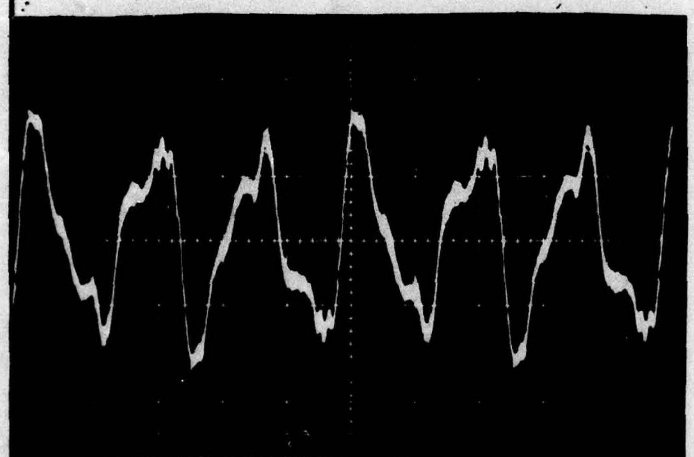


400 HZ SINGLE PHASE, THREE WIRE

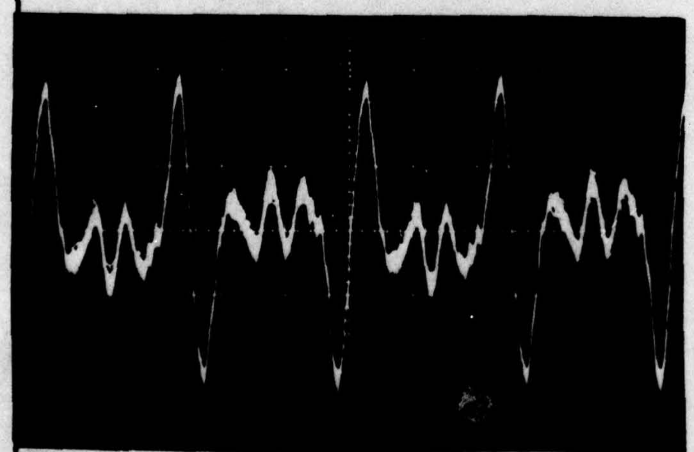
NO LOAD

↕ 0.5V/DIV

↔ 500 μSEC/DIV



10KW, PF=0.8



10KW, PF=1.0

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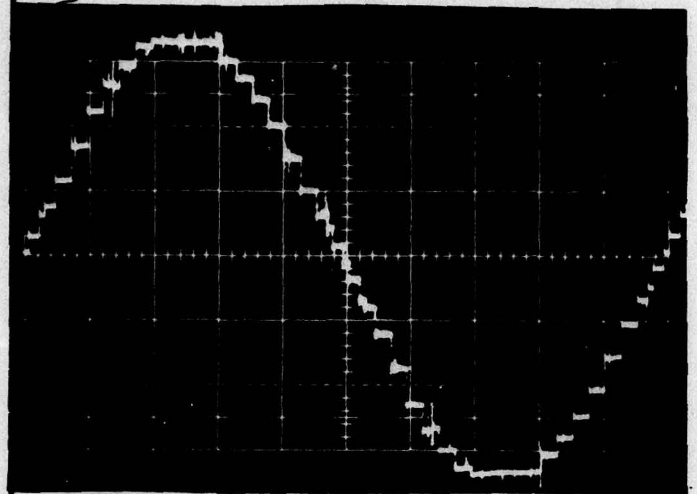


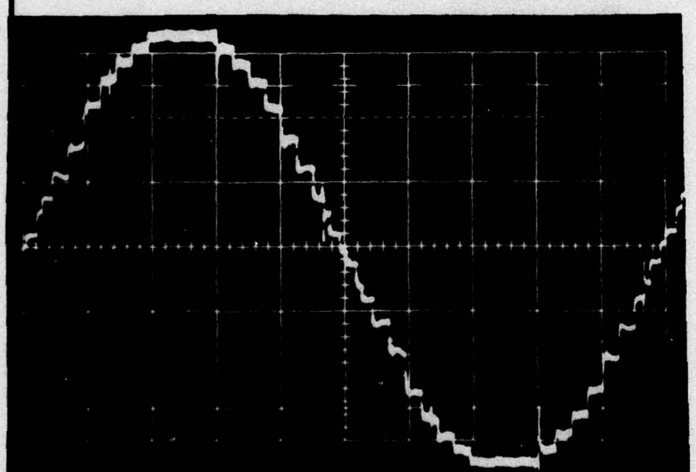
60 HZ SINGLE PHASE, TWO WIRE

NO LOAD

THD = 4.7%

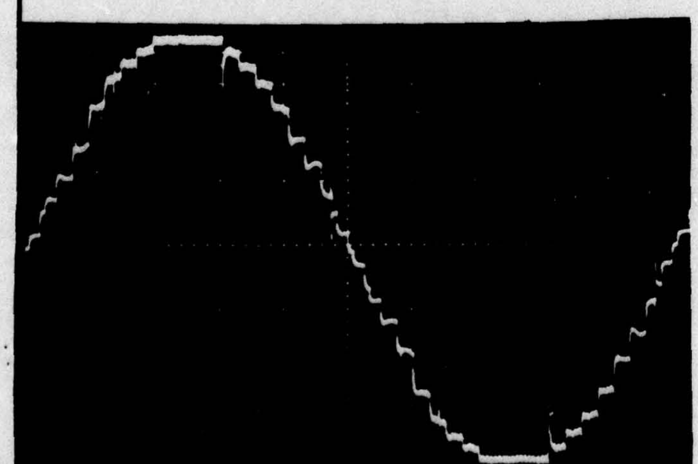
50V/DIV.

(NOTE: NO CAPACITANCE IN OUTPUT FILTER FOR THESE 60HZ, 1Φ, 2WIRE OR 3WIRE TESTS)



6.6KW, PF=1.0

THD = 4.4%



10KW, PF=1.0

THD= 4.48%

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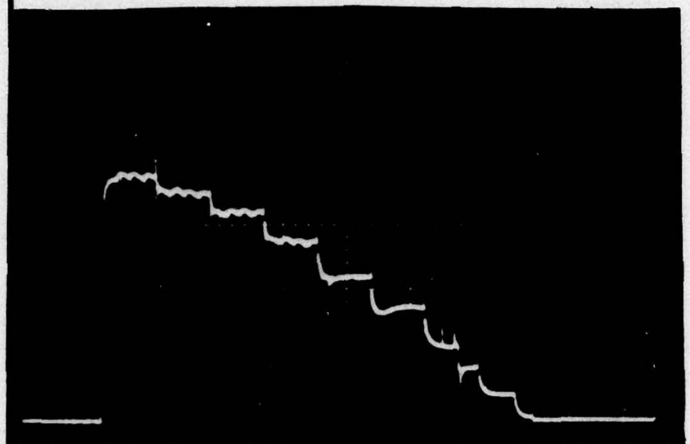
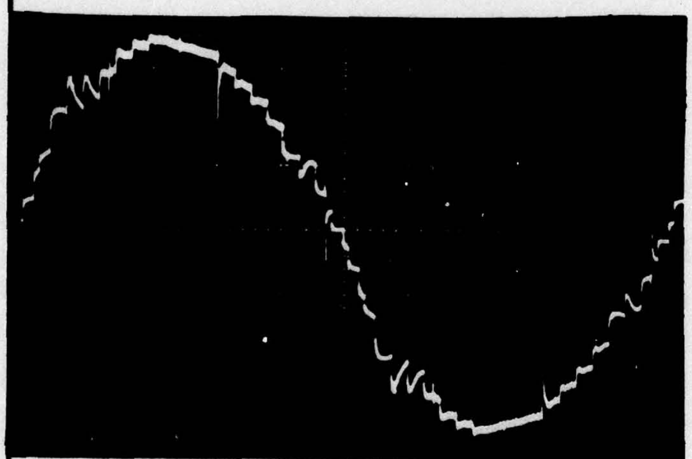


60 HZ SINGLE PHASE, TWO WIRE

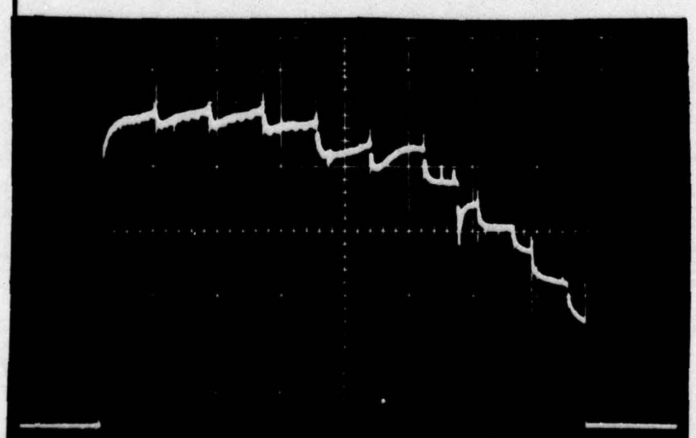
STEP TRANSISTOR CURRENT
↕ 20A./DIV. ↔ 500μSEC/DIV.

10KW, PF=1.0



8.5KW, PF=0.8
OUTPUT VOLTAGE = 110V. RMS
LOAD CURRENT = 111 A. RMS

THD = 6.78%



STEP TRANSISTOR CURRENT FOR ABOVE LOAD.

↕ 20A/DIV.

↔ 500μSEC/DIV.
(MAXIMUM ALLOWABLE CURRENT)

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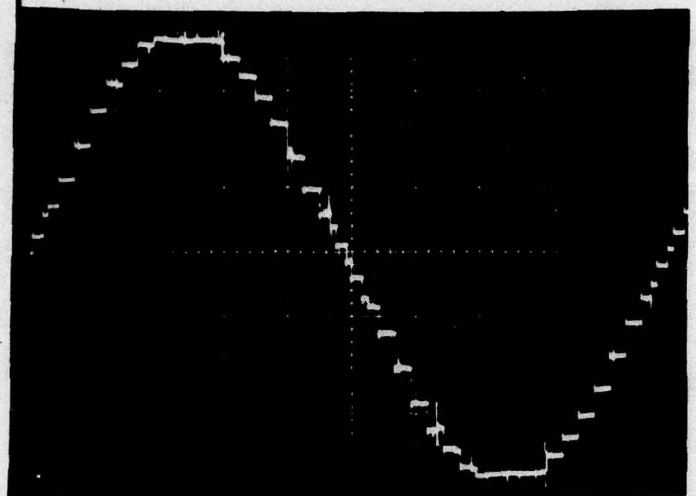
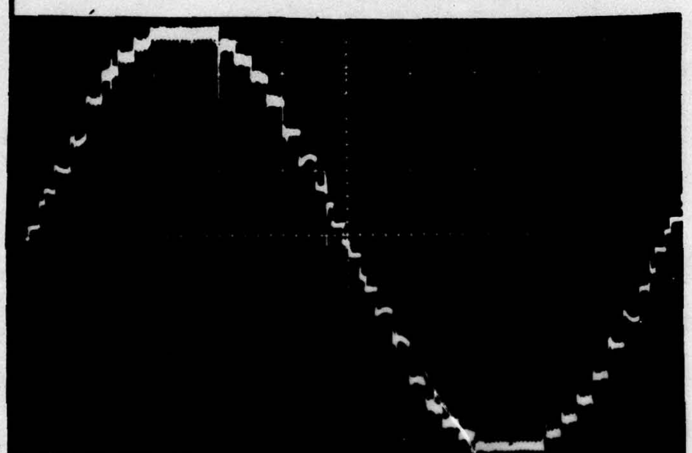


60 HZ SINGLE PHASE, THREE WIRE

NO LOAD

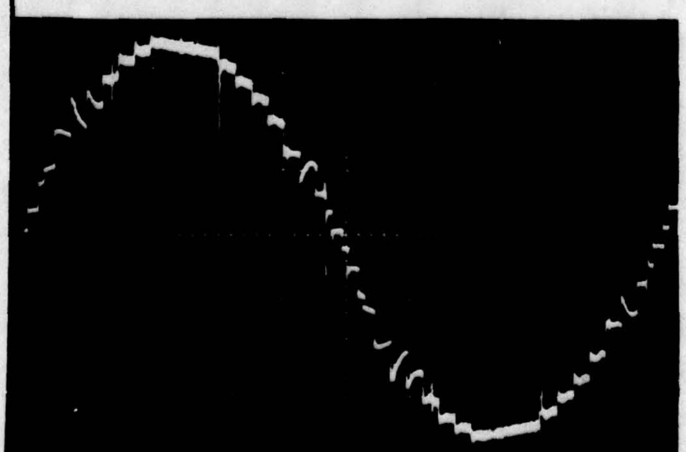
LINE-TO-NEUTRAL VOLTAGE THD= 4.7%

↕ 50V/DIV.



10KW, PF=1.0

THD=5%



8.5KW, PF=0.8

OUTPUT VOLTAGE=110VRMS
CURRENT=55A RMS/LEG

THD=7.2%

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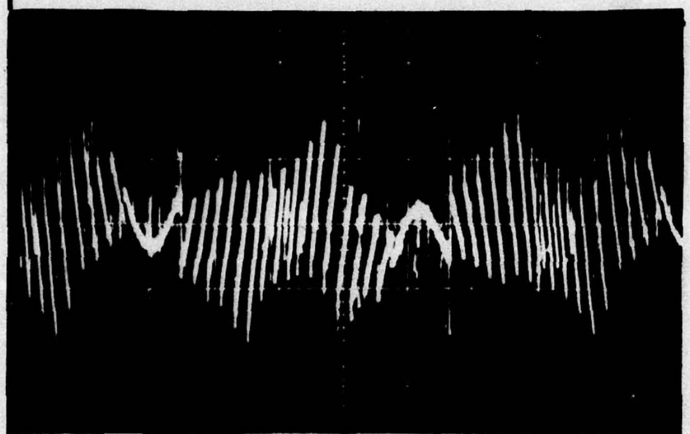
DEVIATION FACTOR

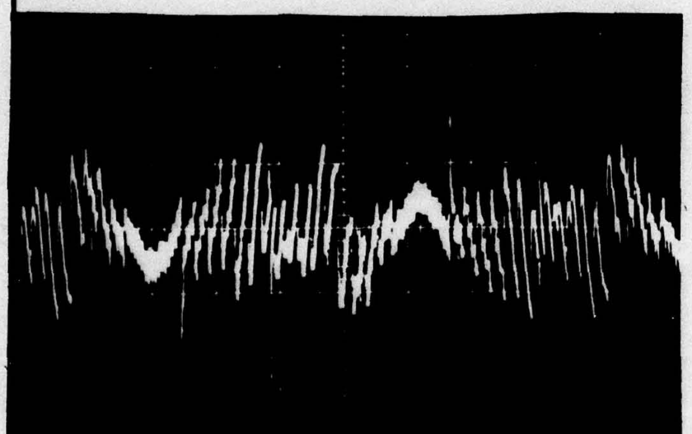


60 HZ SINGLE PHASE, TWO WIRE

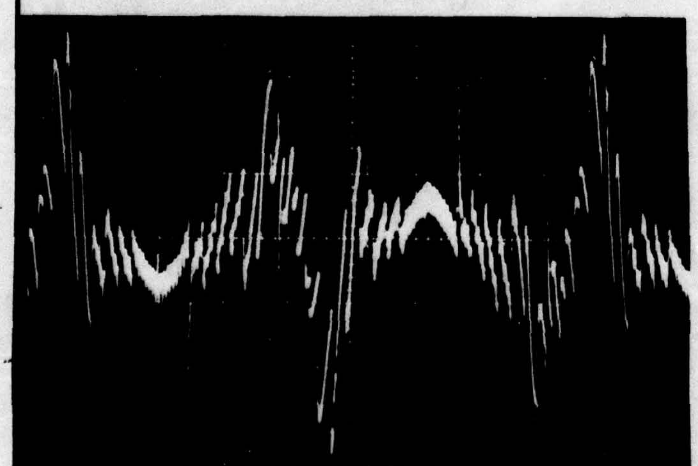
(NOTE: NO CAPACITANCE IN OUTPUT FILTER)

NO LOAD

↕ 10V/DIV. ↔ 2ms/DIV.



10 KW, PF=1.0



8.5 KW, PF = 0.8

DISTRIBUTION:

MEASUREMENTS OF INDIVIDUAL HARMONICS

400HZ, SINGLE PHASE, TWO WIRE

10KW, PF= 0.8

| HARMONIC NUMBER | FREQUENCY KHZ | PERCENT OF FUND. |
|---|---|---|
| 1 | 0.4 | 100% |
| 3 | 1.2 | 4.0 |
| 5 | 2.0 | 2.4 |
| 7 | 2.8 | 2.0 |
| 11 | 4.4 | 0.85 |
| 13 | 5.2 | 0.23 |
| 29 | 11.6 | 0.16 |
| 31 | 12.4 | 0.10 |
| 35 | 14.0 | 0.15 |
| 37 | 14.8 | 0.19 |
| 41 | 16.4 | 0.25 |

COMPUTED THD = 5.17%

MEASUREMENTS MADE WITH HP WAVE ANALYZER 302A

TOTAL HARMONIC DEVIATION (THD) IS DEFINED

$$AS = 100\sqrt{\frac{E_w^2}{E_f^2} - 1}$$

WHERE $E_w$ = RMS VALUE OF STEPPED WAVEFORM

$E_f$ = RMS VALUE OF WAVEFORM FUNDAMENTAL

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MEASUREMENTS OF INDIVIDUAL HARMONICS

60 HZ, SINGLE PHASE, THREE WIRE. NO LOAD

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND. |
|---|---|---|
| 1 | 60 | 100 |
| 3 | 180 | 1.3 |
| 5 | 300 | 1.5 |
| 7 | 420 | 0.42 |
| 9 | 540 | 0.15 |
| 11 | 660 | 1.0 |
| 13 | 780 | 0.17 |
| 15 | 900 | — |
| 17 | 1020 | 0.2 |
| 19 | 1140 | 0.2 |
| 21 | 1260 | — |
| 23 | 1380 | 0.11 |
| 25 | 1500 | 0.17 |
| 27 | 1620 | — |
| 29 | 1740 | 0.28 |
| 31 | 1860 | 0.23 |
| 33 | 1980 | — |
| 35 | 2100 | 0.16 |
| 37 | 2220 | 1.36 |
| 39 | 2340 | — |
| 41 | 2460 | 2.35 |
| 43 | 2580 | 1.30 |
| 45 | 2700 | — |
| 47 | 2820 | 0.1 |
| 49 | 2940 | 0.17 |
| 51 | 3060 | — |

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT FUND. |
|---|---|---|
| 53 | 3180 | — |
| 55 | 3300 | 0.10 |
| 57 | 3420 | — |
| 59 | 3540 | — |
| 61 | 3660 | — |
| 63 | 3780 | — |
| 65 | 3900 | — |
| 67 | 4020 | — |
| 69 | 4140 | — |
| 71 | 4260 | — |
| 73 | 4380 | — |
| 75 | 4500 | — |
| 77 | 4620 | 0.64 |
| 79 | 4740 | 1.2 |
| 81 | 4860 | — |
| 83 | 4980 | — |
| 85 | 5100 | 0.6 |
| 87 | 5220 | — |
| 91 | 5460 | 0.3 |
| 119 | 7140 | 0.8 |
| 121 | 7260 | 0.8 |
| 157 | 9420 | 0.3 |

NO CAPACITORS IN OUTPUT FILTER

COMPUTED THD = 4.27%

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## MEASUREMENTS OF INDIVIDUAL HARMONICS

60HZ, SINGLE PHASE, THREE WIRE. 85 KW PF=0.8

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND. | HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND |
|---|---|---|---|---|---|
| 1 | 60 | 100 | 65 | 3900 | 0.36 |
| 3 | 180 | 4.2 | 67 | 4020 | 0.24 |
| 5 | 300 | 2.2 | 71 | 4260 | 0.3 |
| 7 | 420 | 2.5 | 73 | 4380 | 0.3 |
| 9 | 540 | 1.2 | 77 | 4620 | 1.1 |
| 11 | 660 | 0.61 | 79 | 4740 | 1.5 |
| 13 | 780 | 1.45 | 83 | 4980 | 0.45 |
| 15 | 900 | 0.5 | 85 | 5100 | 0.3 |
| 17 | 1020 | 0.8 | 89 | 5340 | 0.3 |
| 19 | 1140 | 0.64 | 95 | 5700 | 0.2 |
| 21 | 1260 | 0.4 | 97 | 5820 | 0.24 |
| 23 | 1380 | 0.4 | 99 | 5940 | 0.25 |
| 25 | 1500 | 0.57 | 101 | 6060 | 0.2 |
| 29 | 1740 | 0.46 | 105 | 6300 | 0.24 |
| 31 | 1860 | 0.3 | 107 | 6420 | 0.3 |
| 33 | 1980 | 0.2 | 111 | 6660 | 0.26 |
| 35 | 2100 | 0.3 | 117 | 6900 | 0.3 |
| 37 | 2220 | 1.5 | 119 | 7140 | 1.1 |
| 39 | 2340 | 0.43 | 121 | 7260 | 0.72 |
| 41 | 2460 | 2.5 | 125 | 7500 | 0.25 |
| 43 | 2580 | 1.2 | 131 | 7860 | 0.18 |
| 45 | 2700 | 0.3 | 133 | 7980 | 0.2 |
| 47 | 2820 | 0.3 | 137 | 8220 | 0.25 |
| 49 | 2940 | 0.35 | 139 | 8340 | 0.2 |
| 51 | 3060 | 0.12 | 143 | 8580 | 0.25 |
| 53 | 3180 | 0.32 | 145 | 8700 | 0.25 |
| 55 | 3300 | 0.2 | 149 | 8940 | 0.24 |
| 59 | 3540 | 0.26 | 151 | 9060 | 0.24 |
| 61 | 3660 | 0.25 | 153 | 9180 | 0.5 |

[illegible] OUTPUT. COMPUTED THD= 7.26%

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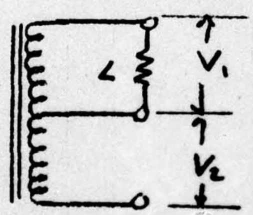
## DC VOLTAGE COMPONENT

SINGLE PHASE, TWO WIRE

| FREQUENCY HZ | V V.RMS | I A.RMS | PF | LOAD KW | $V_{DC}$ MV. |
|---|---|---|---|---|---|
| 400 | 120.2 | 0 | — | 0 | +16 |
| 400 | 120.2 | 83.5 | 1.0 | 10 | +4 |
| 400 | 120.3 | 104 | 0.8 | 10 | +5 |
| 60 | 120.12 | 0 | — | 0 | -13 |
| 60 | 120.5 | 84 | 1.0 | 10 | -10 |
| 60 | 120.1 | N.A. | 0.8 | 8.5 | -5 |

SINGLE PHASE, THREE WIRE VOLTAGE BALANCE




1φ OUTPUT TRANSFORMER.

| $V_1$ VRMS | $V_2$ VRMS | LOAD KW, PF=0.8 | |
|---|---|---|---|
| 121.9 | 121.9 | — | 400 HZ |
| 121.6 | 122.2 | 2.2 | 400 HZ |
| 121.3 | 122.4 | 4.4 | 400 HZ |
| 121.4 | 122.4 | 5.8 | 400 HZ |
| 120.2 | 120.2 | — | 60 HZ |
| 120.2 | 121.4 | 2.2 | 60 HZ |
| 120.3 | 122.4 | 4.4 | 60 HZ |
| 120.4 | 123.0 | 5.8 | 60 HZ |

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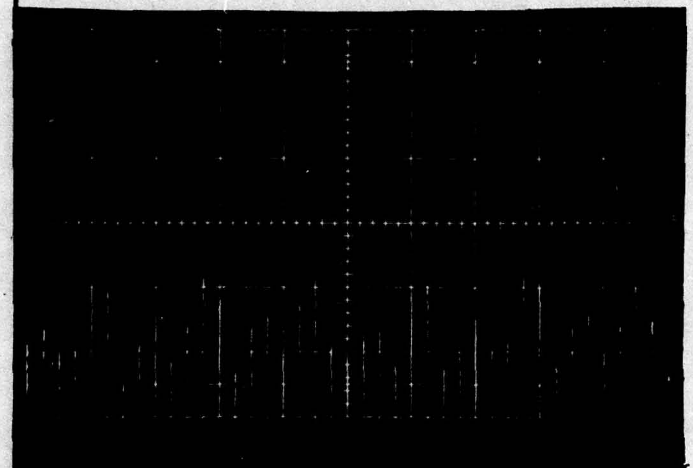
3.24.1.7 VOLTAGE MODULATION

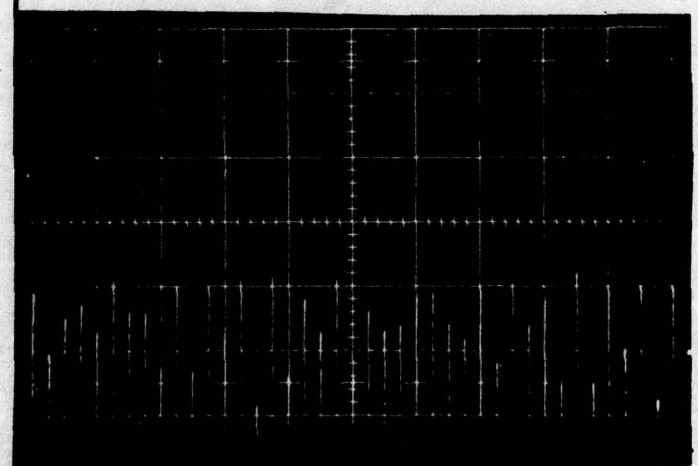


400 HZ SINGLE PHASE, TWO WIRE

NO LOAD

↕ 2V/DIV.

↔ 10MS/DIV.



10KW, PF=1.0

10KW, PF=0.8

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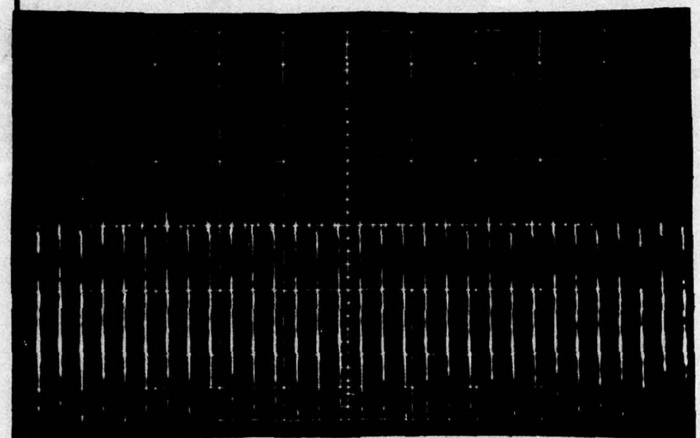
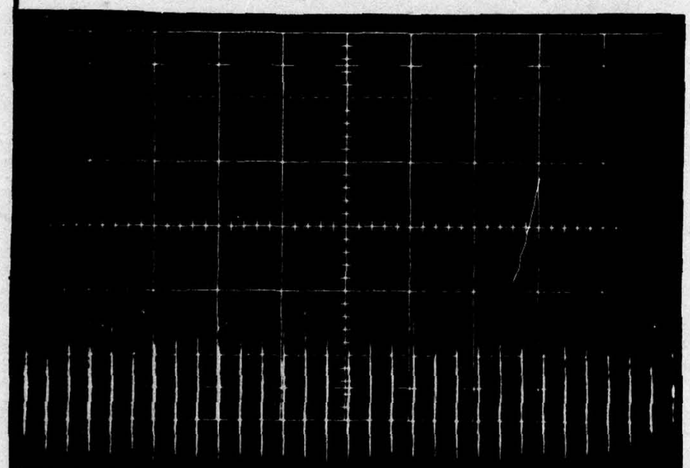


60HZ SINGLE PHASE, TWO WIRE

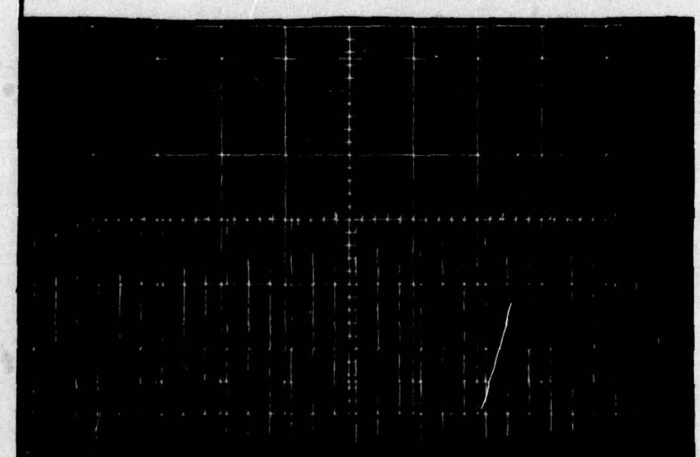
NO LOAD

↕ 2V/DIV.

↔ 50MS/DIV.



10KW, PF=1.0



8.5KW, PF=0.8

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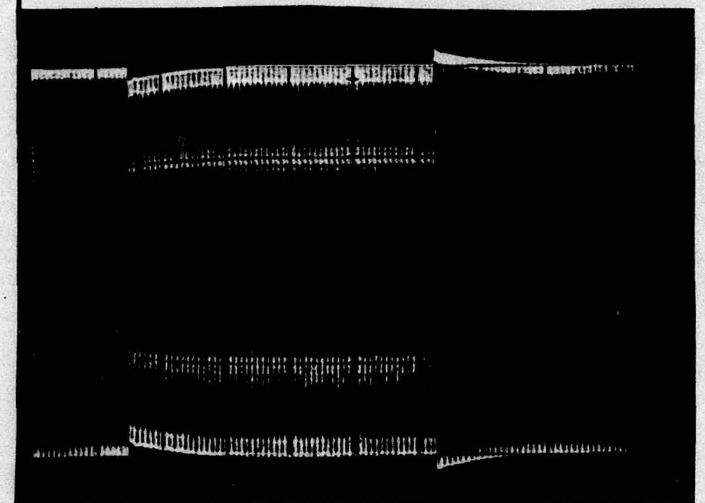
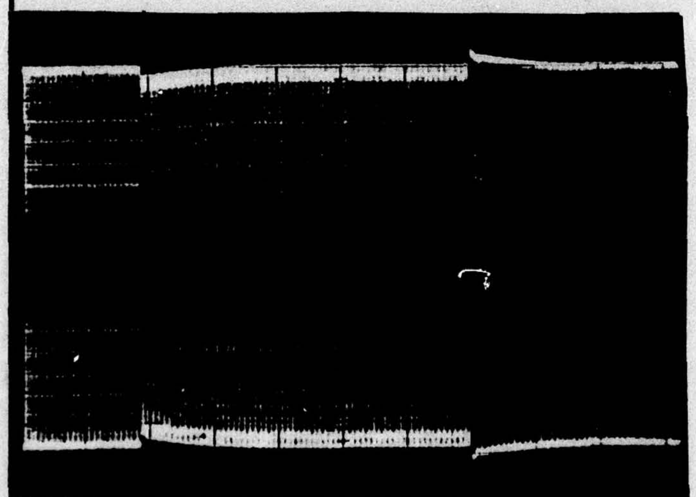
3.24.1.12 TRANSIENT VOLTAGE PERFORMANCE

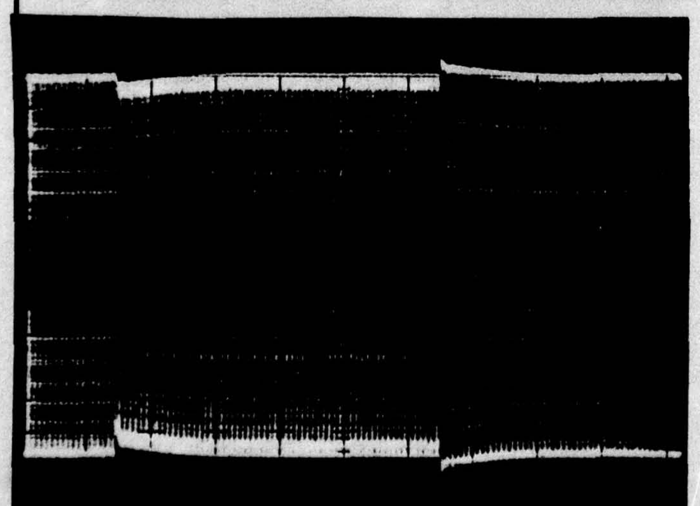


400 HZ SINGLE PHASE, TWO WIRE

1/4 LOAD, PF=0.8

↔ 0.2SEC/DIV.





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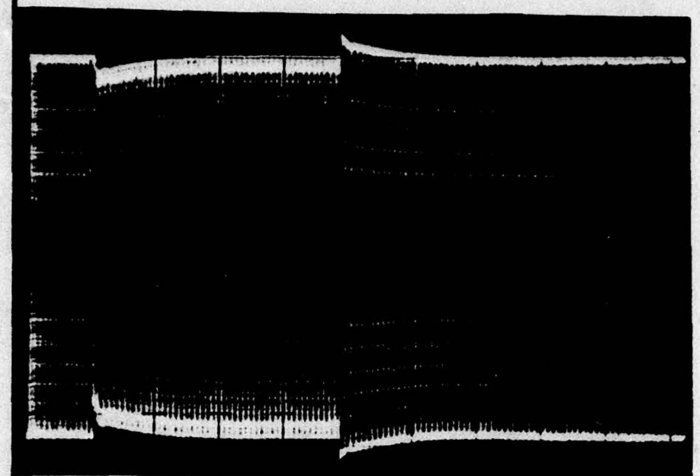
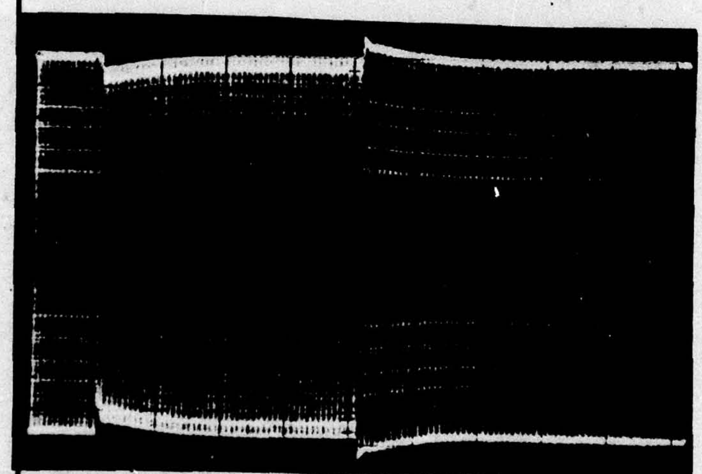
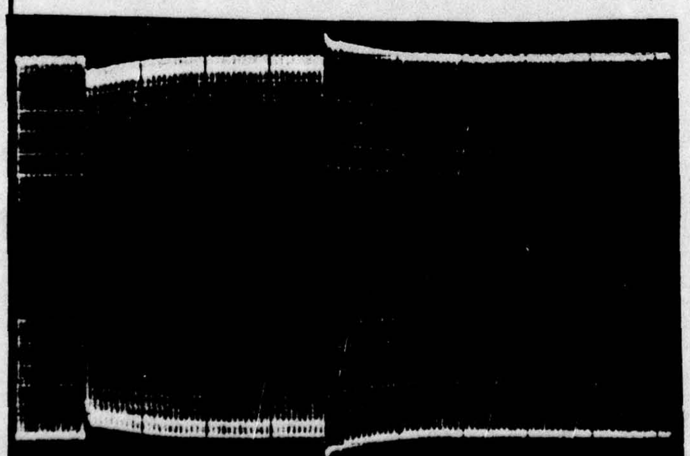


400 HZ SINGLE PHASE, TWO WIRE

1/2 LOAD, PF = 0.8

↔ 0.2 SEC/DIV.





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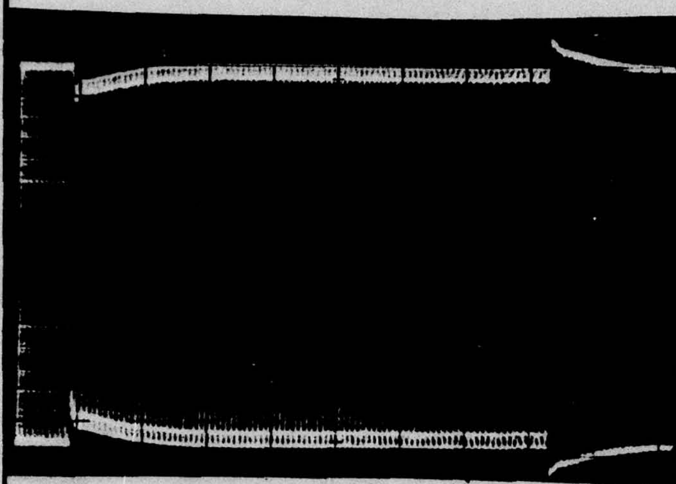
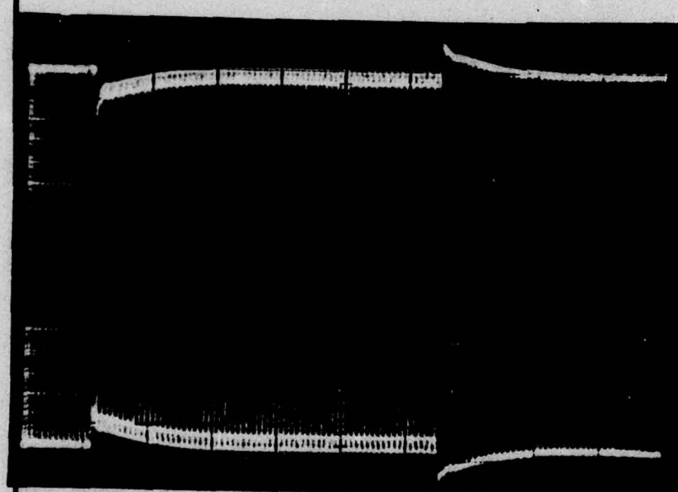
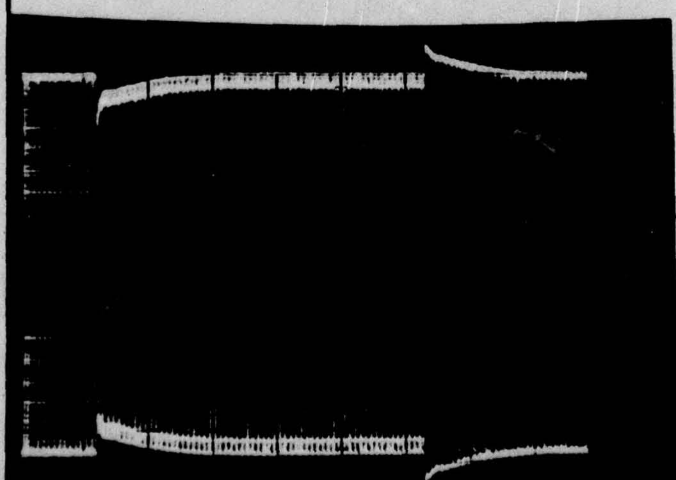


400 HZ SINGLE PHASE, TWO WIRE

3/4 LOAD, PF=0.8

↔ 0.2SEC/DIV.





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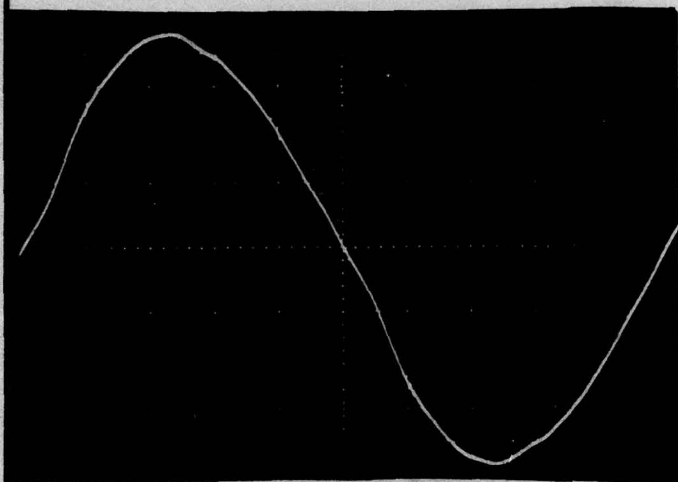
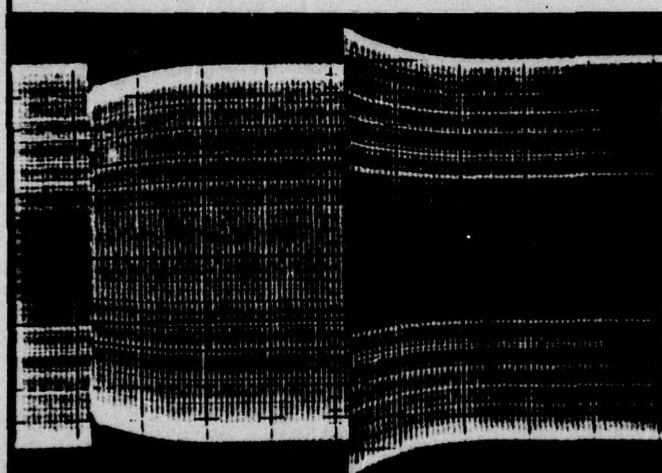


400 HZ SINGLE PHASE, TWO WIRE

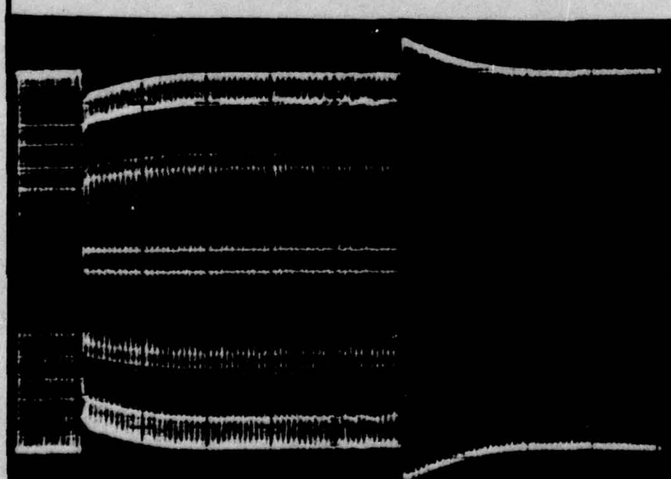
10 KW, PF = 0.8

THD = 4.3%



FULL LOAD, PF = 0.8

← 0.2 SEC/DIV.



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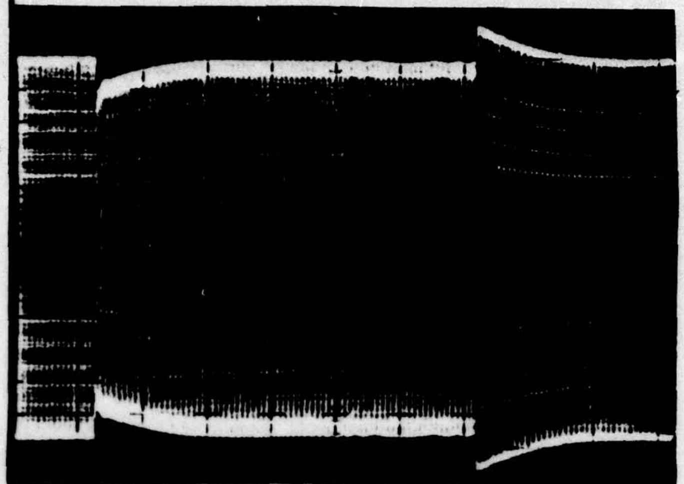

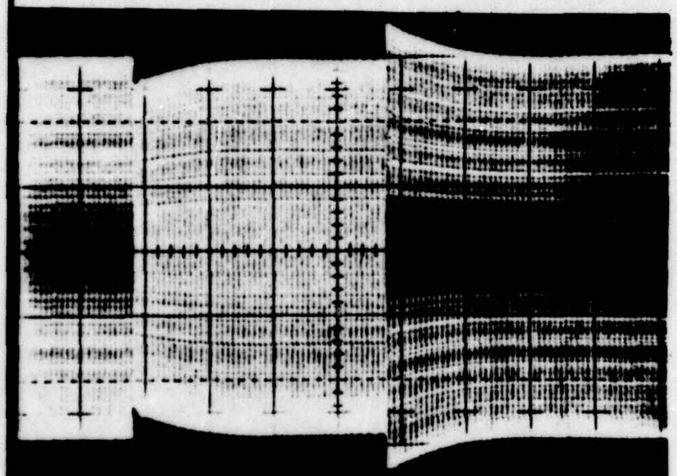

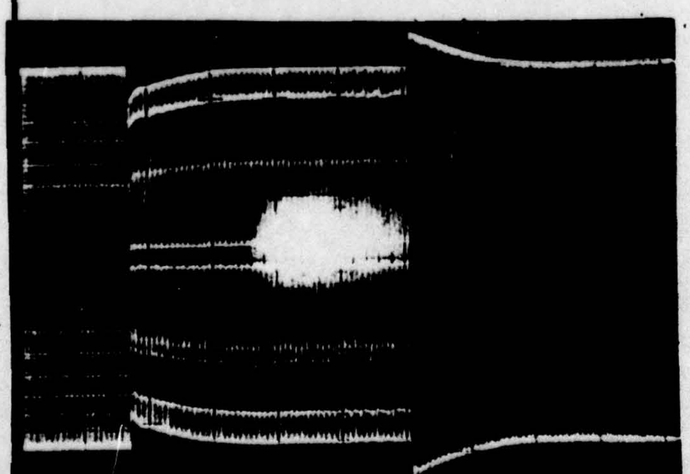

400 HZ SINGLE PHASE, TWO WIRE

FULL LOAD, PF=0.8

↔ 0.2 SEC/DIV.

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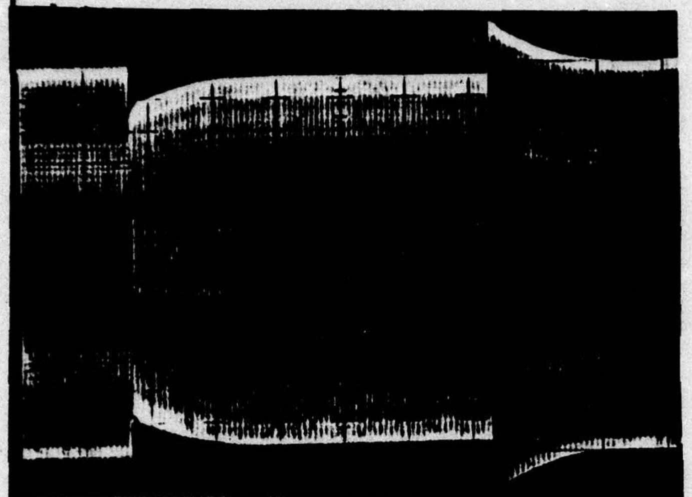
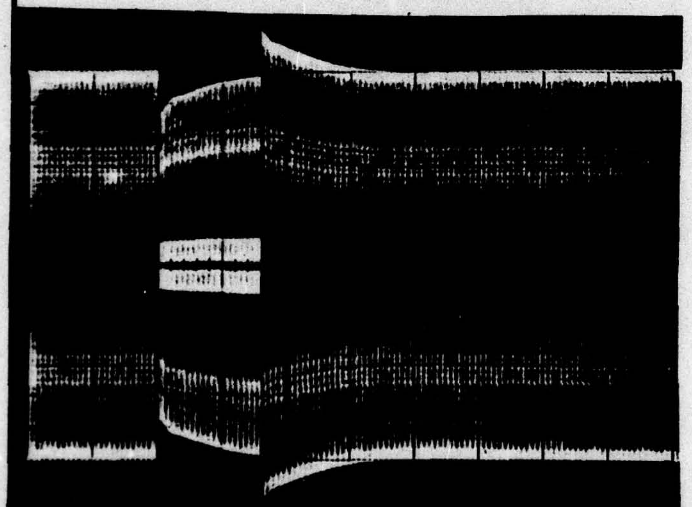


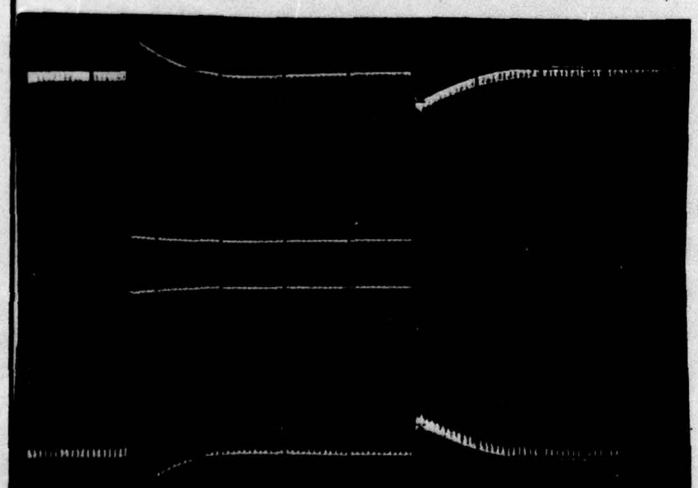
400 HZ SINGLE PHASE, TWO WIRE

1.25 LOAD, PF = 0.8

↔ 0.2 SEC/DIV.



2 P.U., PF = 0.4



2 P.U., PF = 0.1

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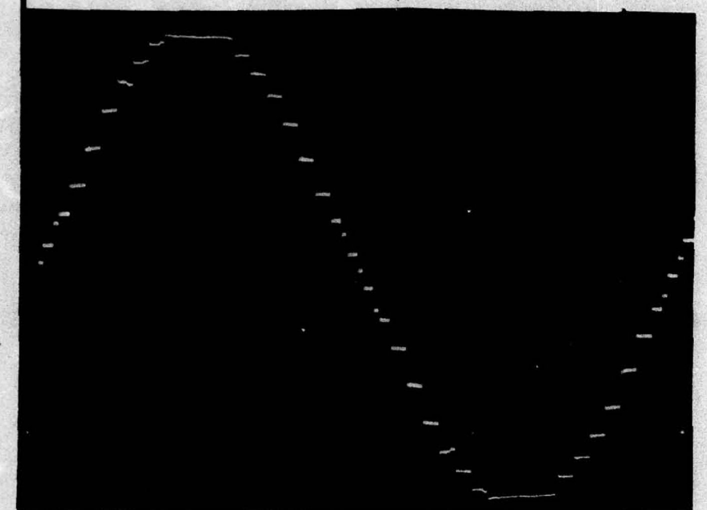
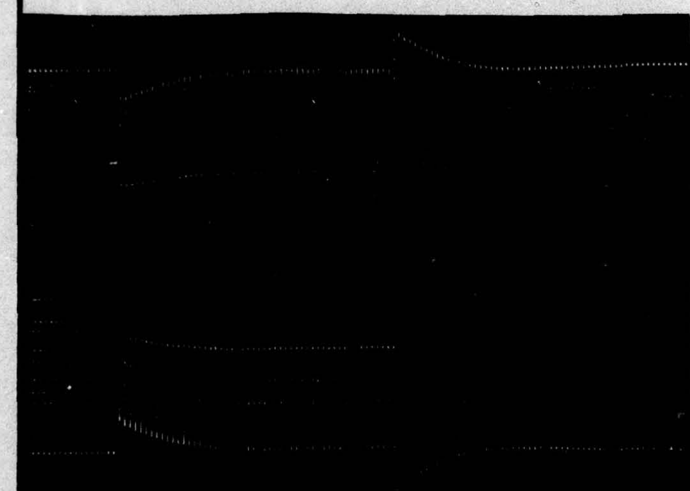


60 HZ SINGLE PHASE, TWO WIRE

NO LOAD

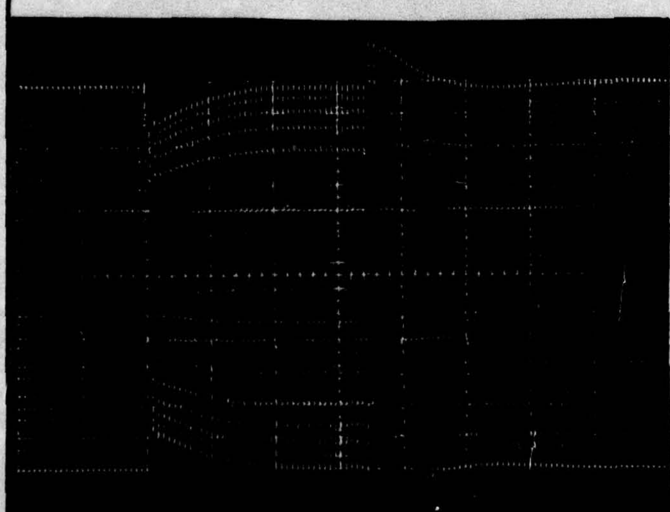
THD = 4.7%

(NOTE: NO CAPACITANCE IN OUTPUT OF CONVERTER)



1/4 LOAD, PF = 0.8

⟷ 0.2 SEC/DIV.



1/2 LOAD, PF = 1.0

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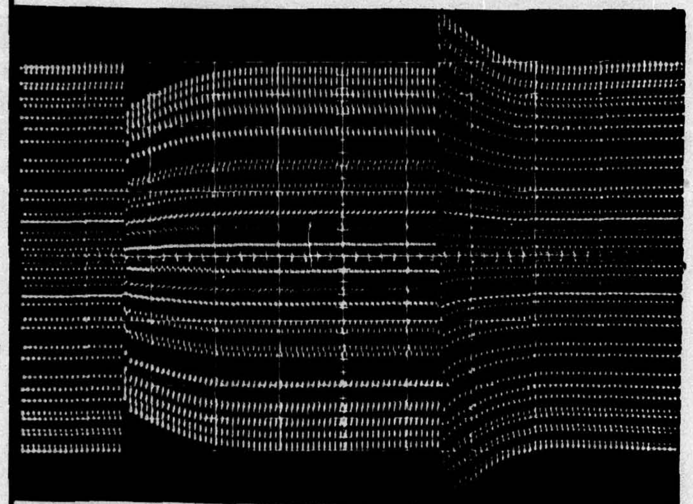
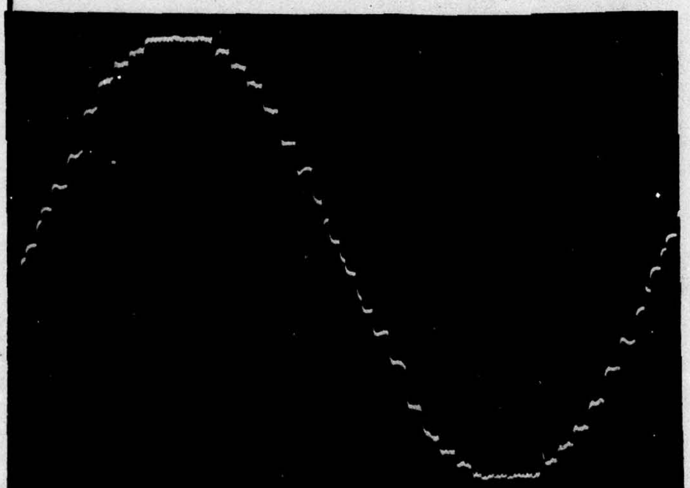


60HZ SINGLE PHASE, TWO WIRE

3/4 LOAD, PF=1.0

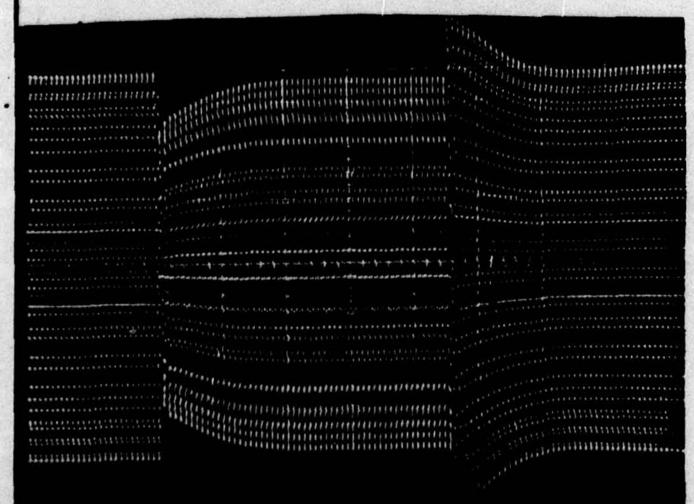
⟷ 0.2SEC/DIV.



10KW, PF=1.0

THD= 4.3%

↕ 50V/DIV.



FULL LOAD, PF=1.0

(NOTE: NO CAPACITANCE IN CONVERTER OUTPUT)

DISTRIBUTION:

3.24.3 EFFICIENCY

| CIRCUIT DESCRIPTION | FREQ. HZ | INPUT POWER WATTS | OUTPUT POWER WATTS | P.F. | LOSSES WATTS | EFF. % # |
|---|---|---|---|---|---|---|
| P.F. CORRECTED; 60MFD L-L → | 400 | 13013 | 11040 | 0.8 | 1973 | 84.8 |
| | 400 | 13170 | 11040 | 1.0 | 2130 | 83.8 |
| | 400 | 3888 | 2231 | 1.0 | 1675 | 57.4 |
| | 400 | 1615 | NO LOAD | — | 1615 | — |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

# DOES NOT INCLUDE RECTIFIER OR OTHER FIXED LOSSES.

DISTRIBUTION:

10 KW FREQUENCY CONVERTER

Test Results Items 0001, 0003, 0004.

Three Phase Performance

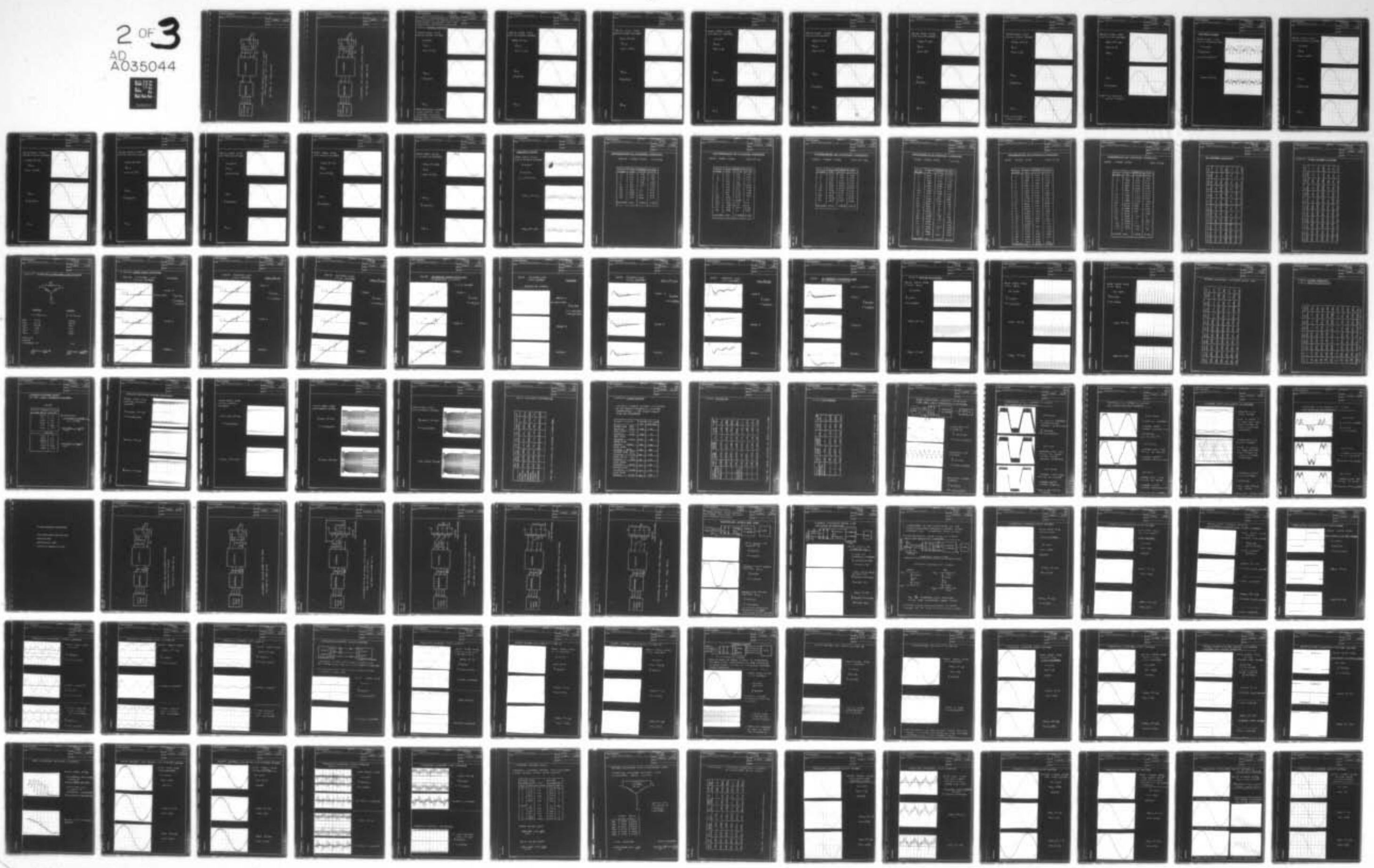
CDRL Item AC02

Modification Nos. P0003 & P0006

Contract No. DAAK02-72-C-0210

AD-A035 044 GENERAL MOTORS CORP GOLETA CALIF DELCO ELECTRONICS DIV F/G 9/5
FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
MAY 74 T CORRY, BARRETT DAAK02-72-C-0210
UNCLASSIFIED R74-40-VOL-2 NL

2 OF 3
AD
A035044



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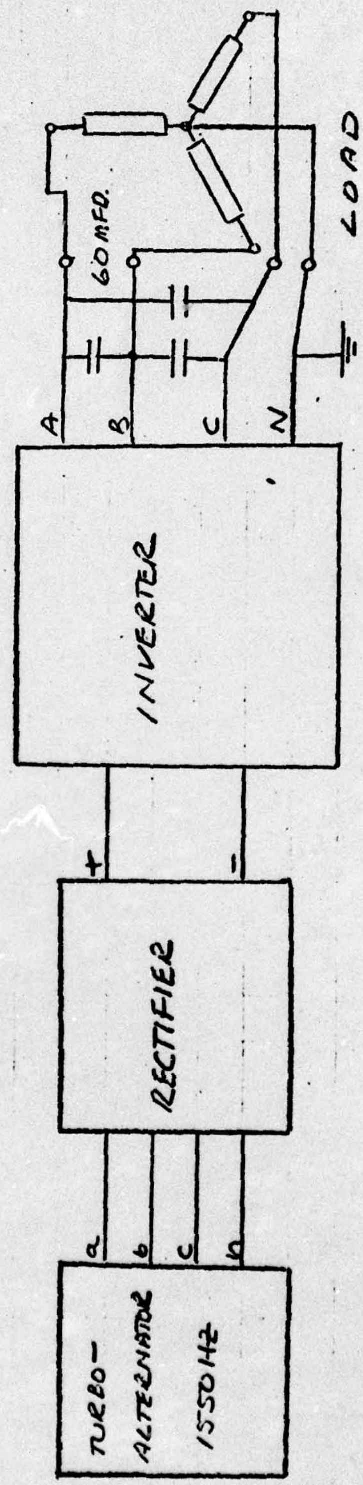


CONNECTIONS FOR 400 HZ, THREE PHASE POWER
(STEP TRANSISTORS NOT CONNECTED)

FOR DATA ON PAGES 38-85

DISTRIBUTION:

DELCO ELECTRONICS

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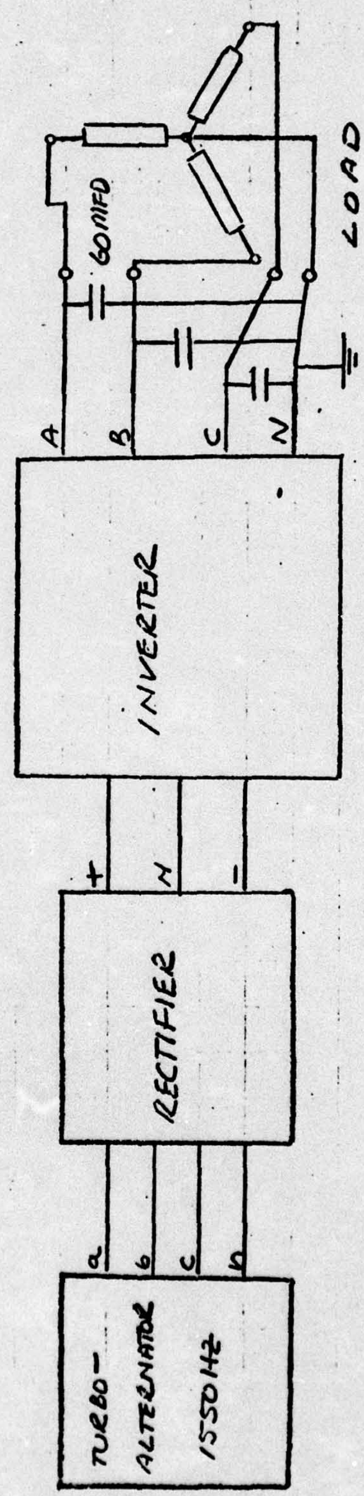


CONNECTIONS FOR 60HZ, THREE PHASE POWER

FOR DATA ON PAGES 38-85

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|---|---|---|---|---|
| TITLE TESTS IN ACCORDANCE WITH ATTACHMENT NO.3 OF CONTRACT NO. DAAK02-72-C-0210 MODIFICATION NOS. P0003 & P0006 AND MIL-STD-705B. ITEMS 0001, 0003, 0004 | | | PREPARED CORRY | DATE 1/15/74 |
| | | | CHECKED | |
| | | | APPROVED | |

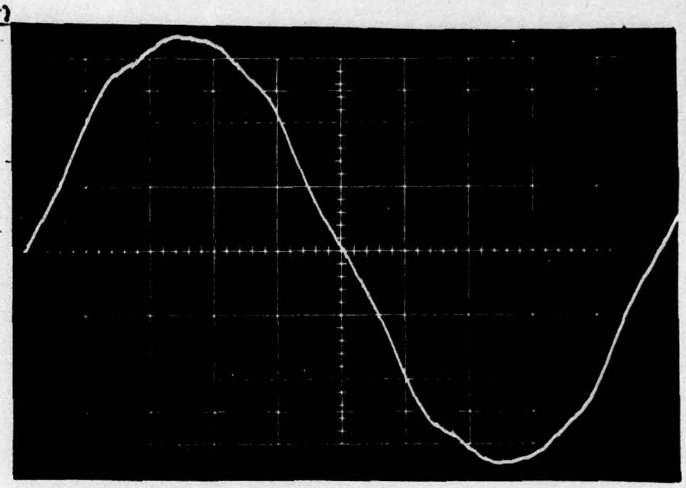
3.24.1.3 VOLTAGE WAVEFORM

400HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

NO LOAD

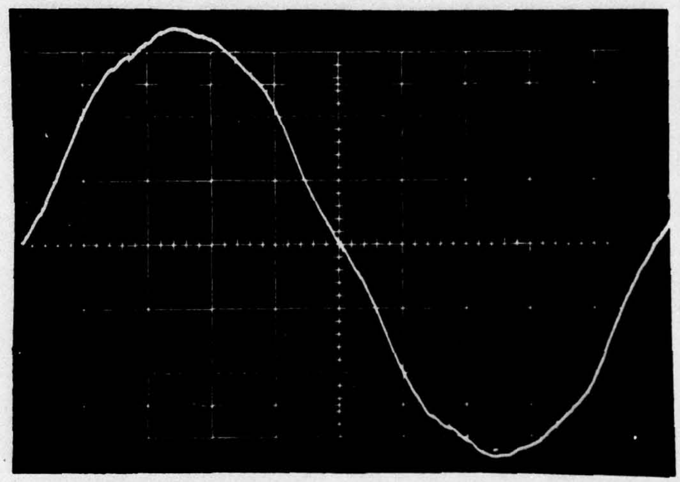
$V_{A-N}$

THD = 3.2%



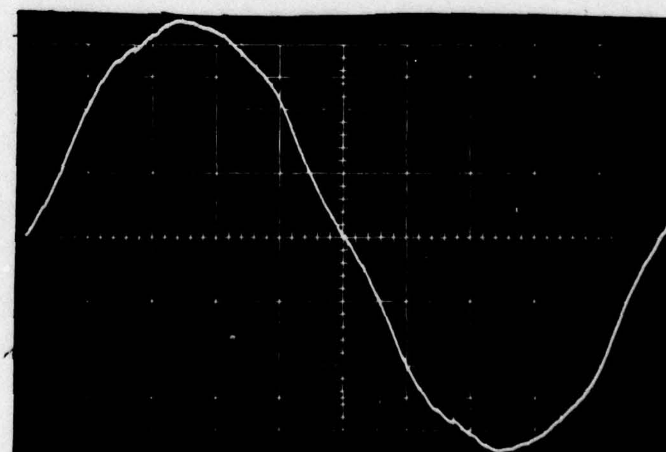
$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$

(NOTE: FREQUENCY CONVERTER INPUT NEUTRAL NOT CONNECTED FOR 400HZ, THREE PHASE OPERATION)



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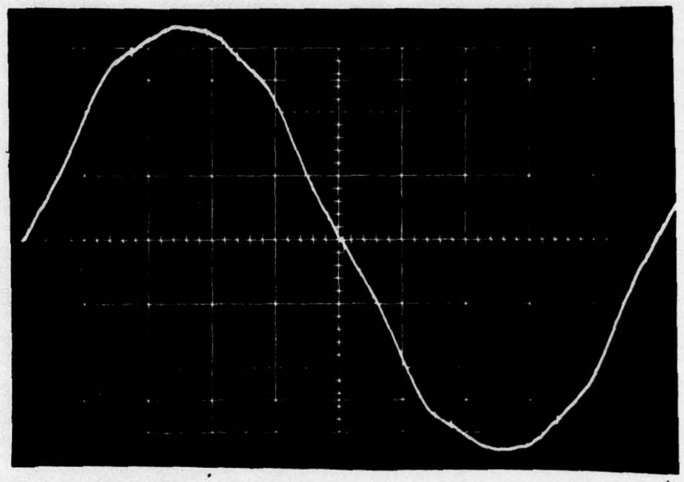
| | | APPROVED | | |

400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF=1.0

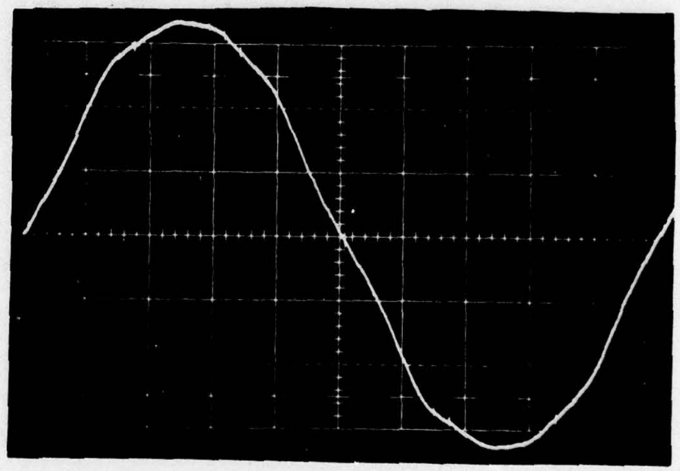
$V_{A-N}$

THD= 3.13%

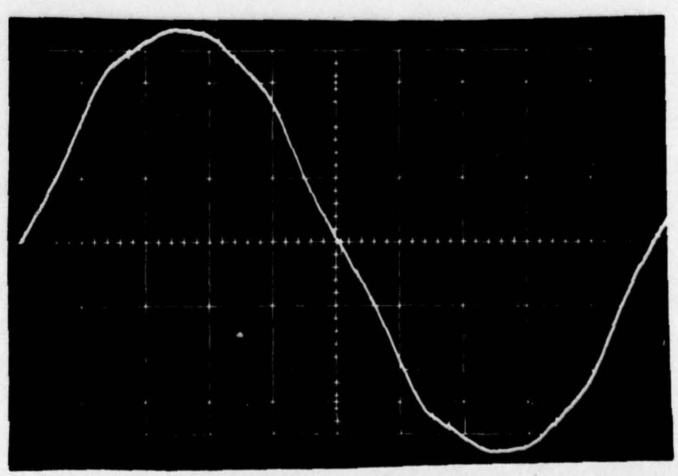


$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$



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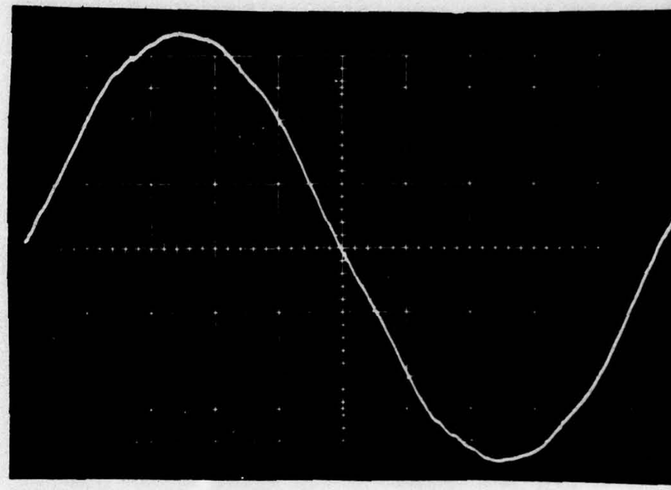
APPROVED

400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF = 0.8

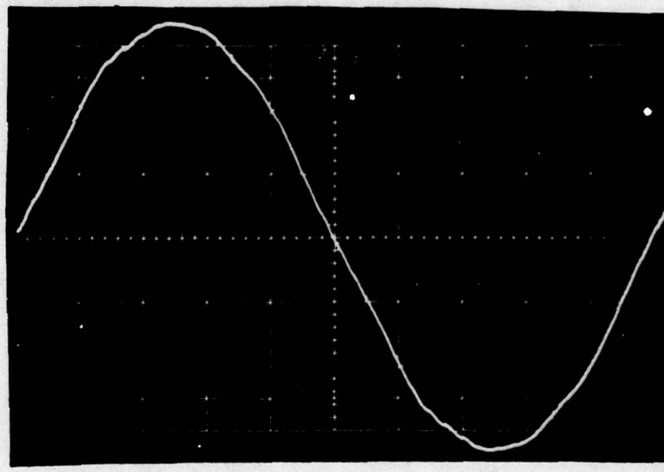
$V_{A-N}$

THD = 1.84%

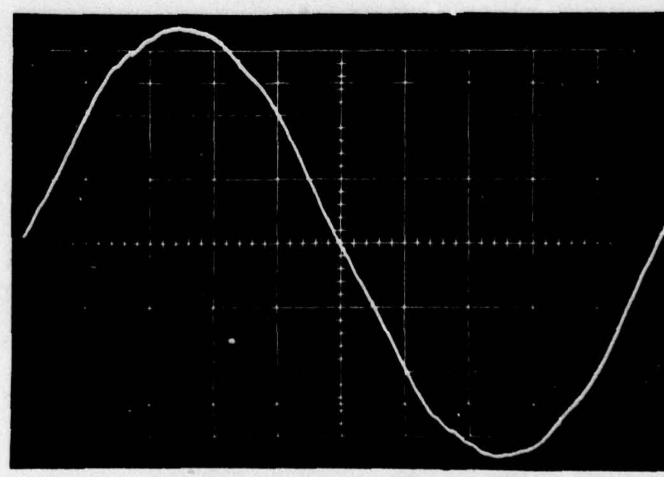


$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$



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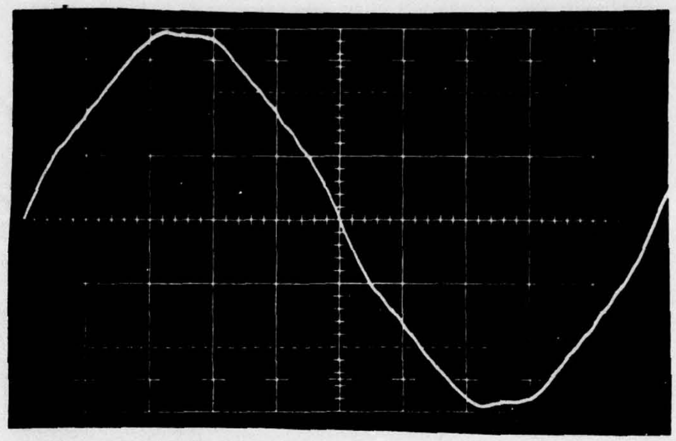
| | | APPROVED | | |

400HZ THREE PHASE
LINE-TO-LINE VOLTAGES

NO LOAD

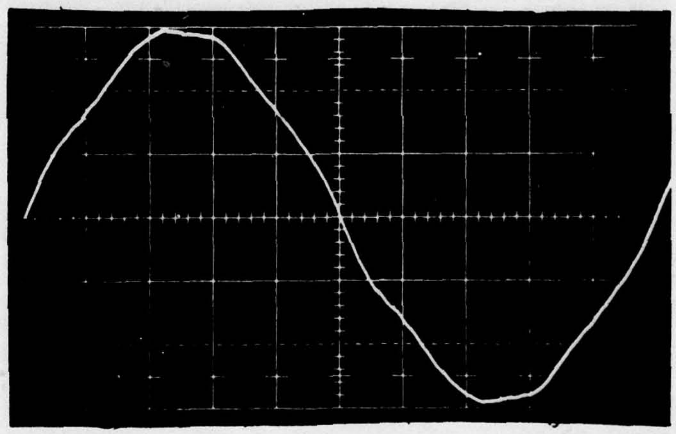
$V_{A-B}$

THD = 3.2%

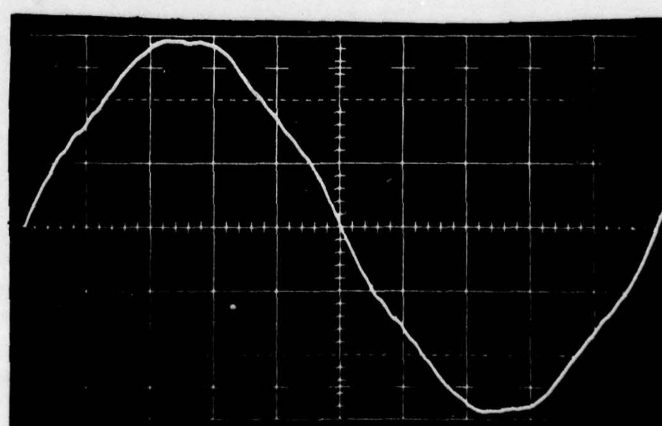


$V_{B-C}$

↕ 100 V/DIV.



$V_{C-A}$



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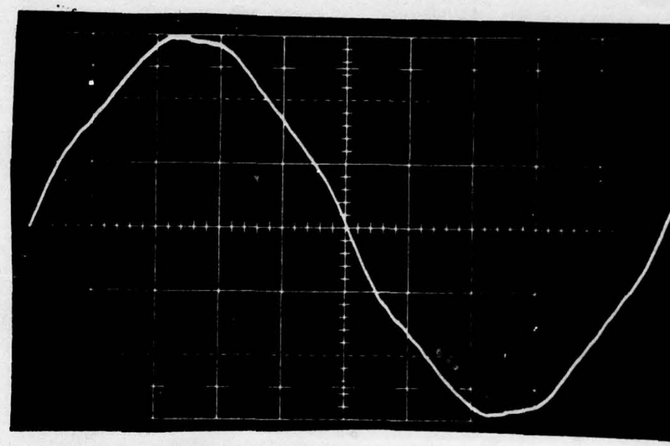
400 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

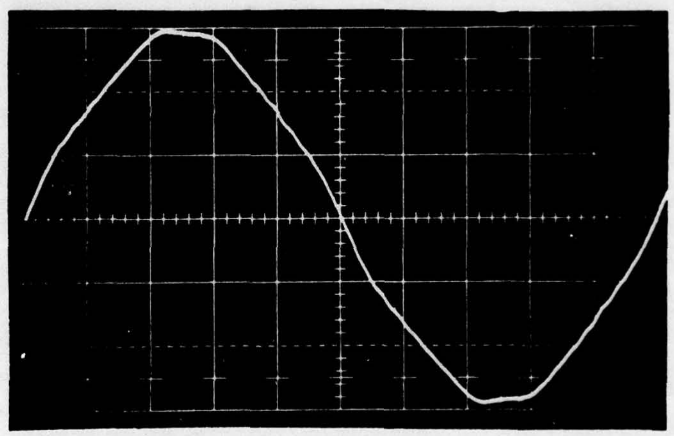
11KW, PF = 1.0

$V_{A-B}$

THD = 3.13%

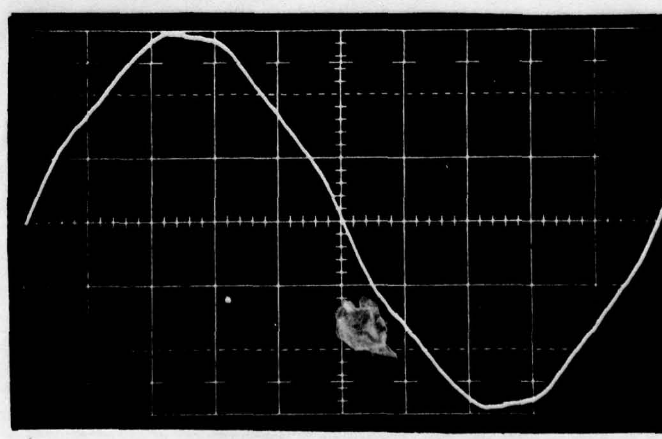


$V_{B-C}$



↕ 100V/DIV.

$V_{C-A}$



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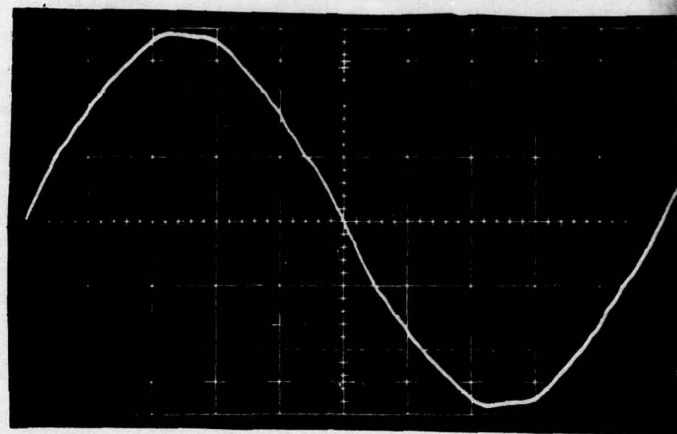
400 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

11KW, PF=0.8

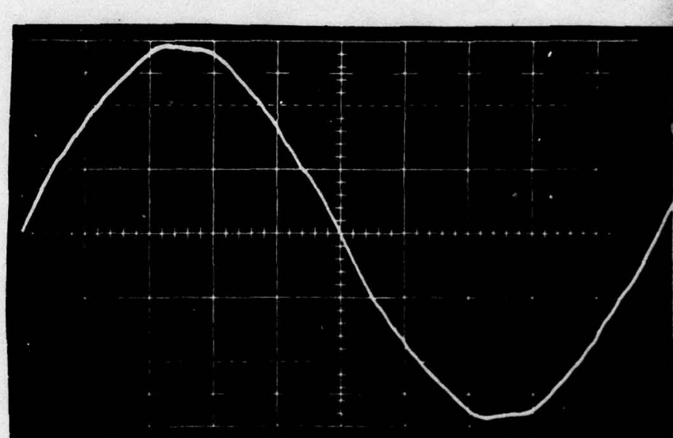
$V_{A-B}$

THD= 1.8%

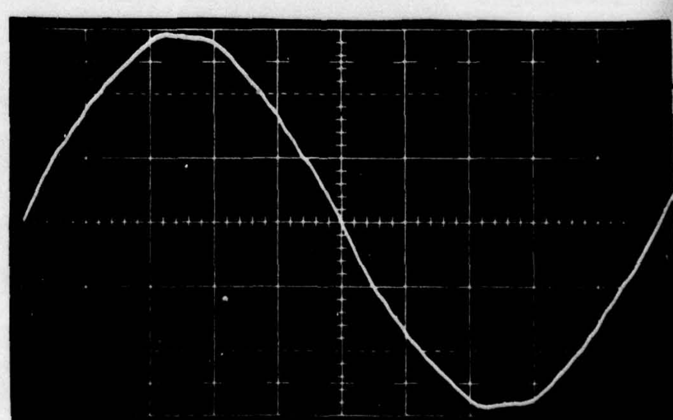


$V_{B-C}$

↕ 100V/DIV.



$V_{C-A}$



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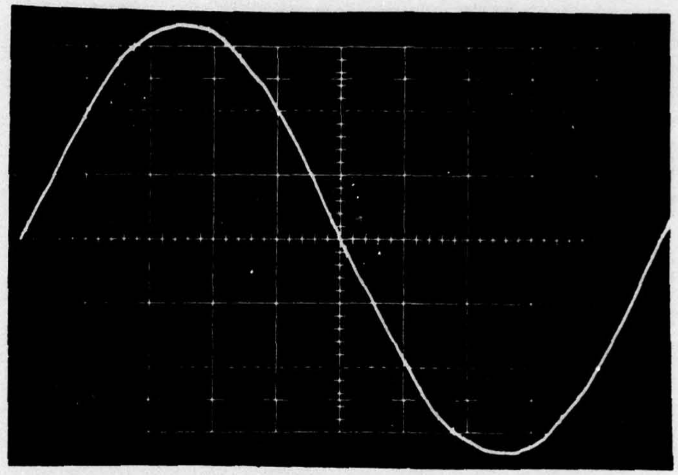
400 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

13 KW, PF=0.8

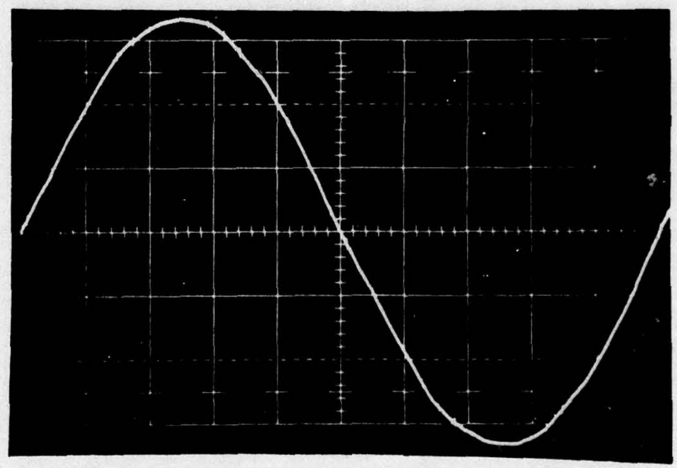
$V_{A-N}$

THD= 1.2%



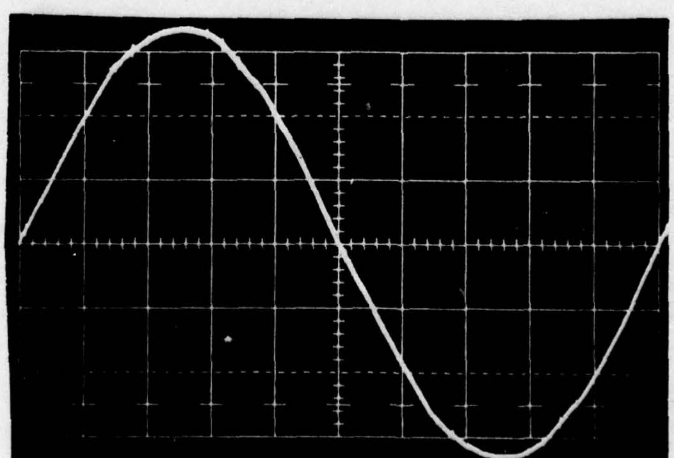
$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$

(NOTE: 7 μH ADDED TO OUTPUT FILTER)



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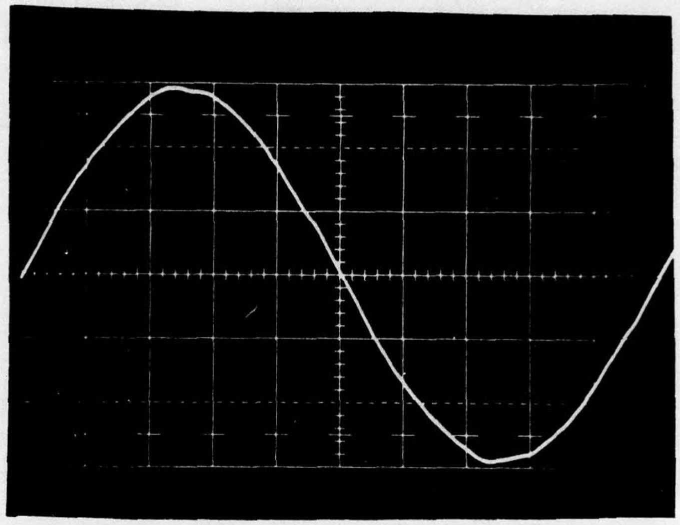
400 HZ THREE PHASE LINE-TO-LINE VOLTAGES

13KW, PF = 0.8

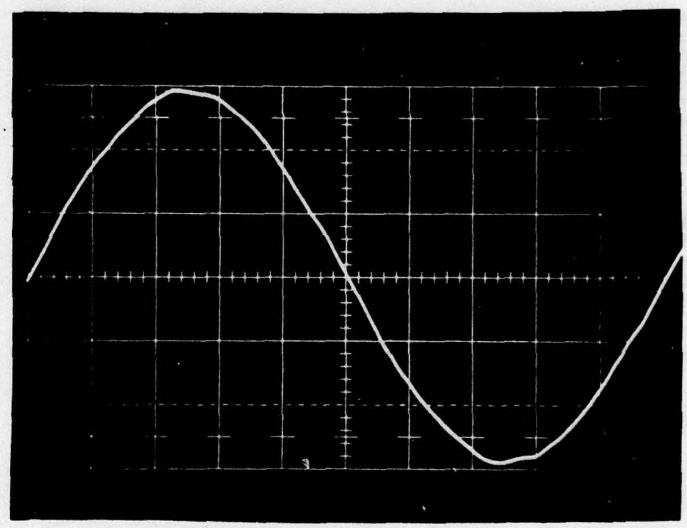
THD = 1.1%

$V_{A-B}$



$V_{B-C}$

↕ 100V/DIV.



(NOTE: 7μH ADDED TO OUTPUT FILTER)

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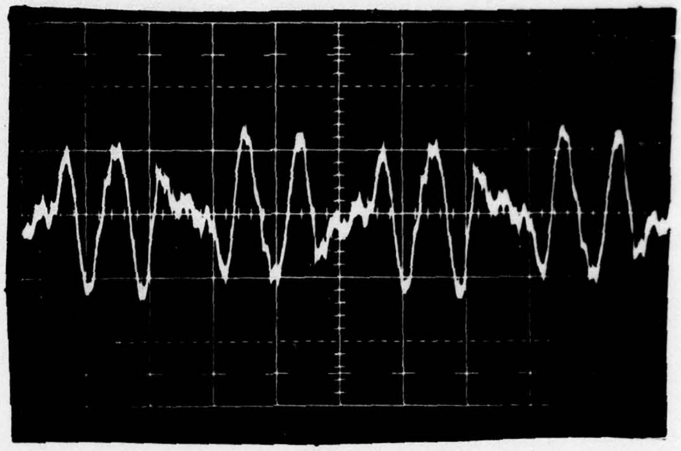
DEVIATION FACTOR

400HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

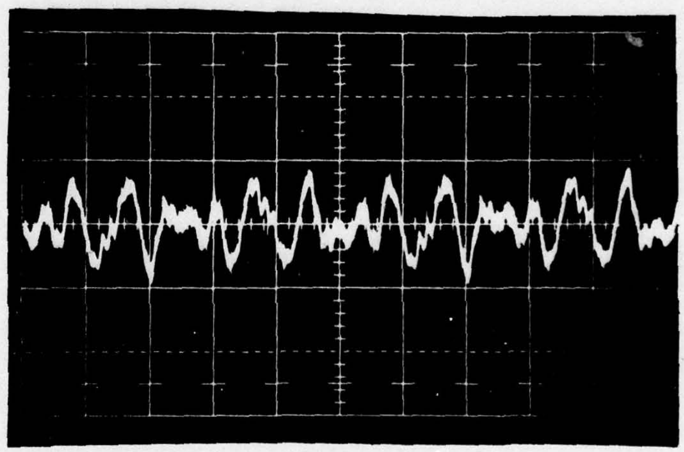
NO LOAD

↕ 0.5V/DIV.

⟷ 500μSEC/DIV.



11KW, PF=0.8



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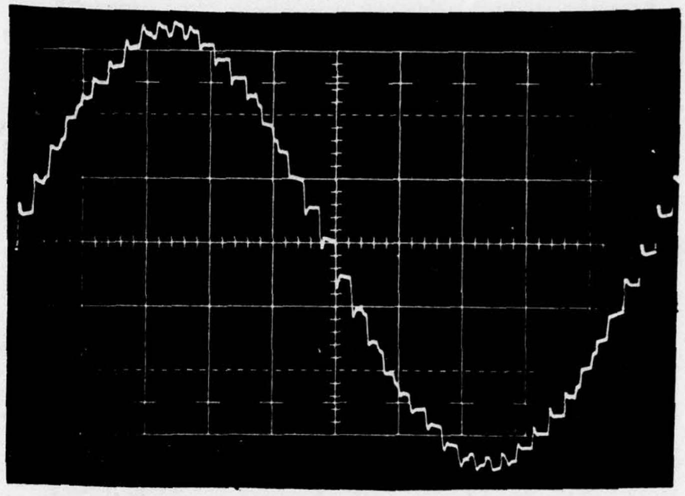
60 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

NO LOAD

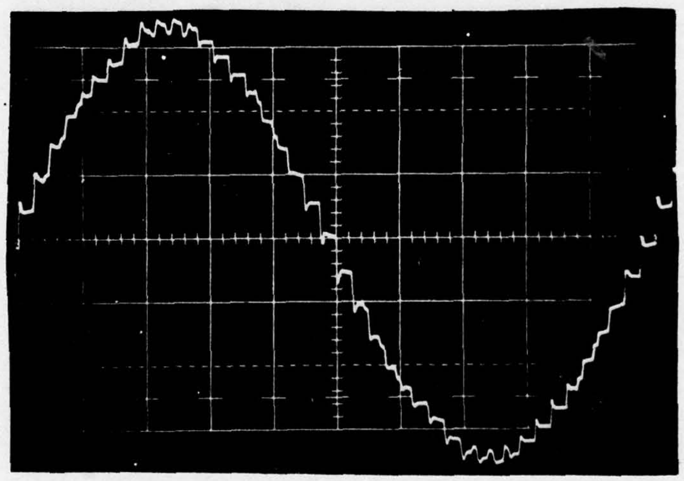
$V_{A-N}$

THD = 4.28%

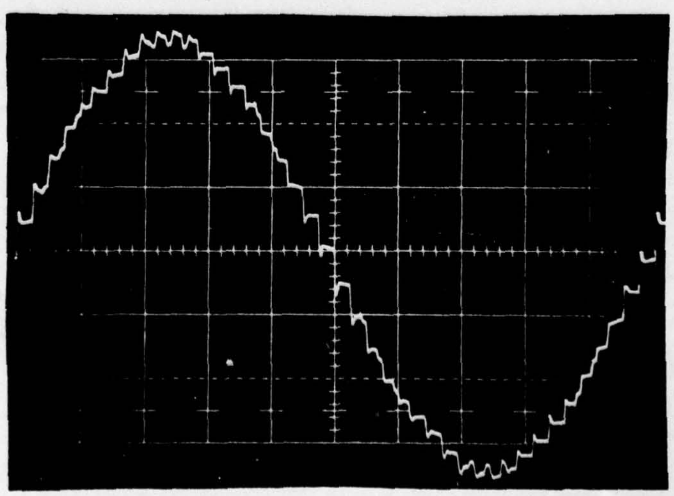


$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$



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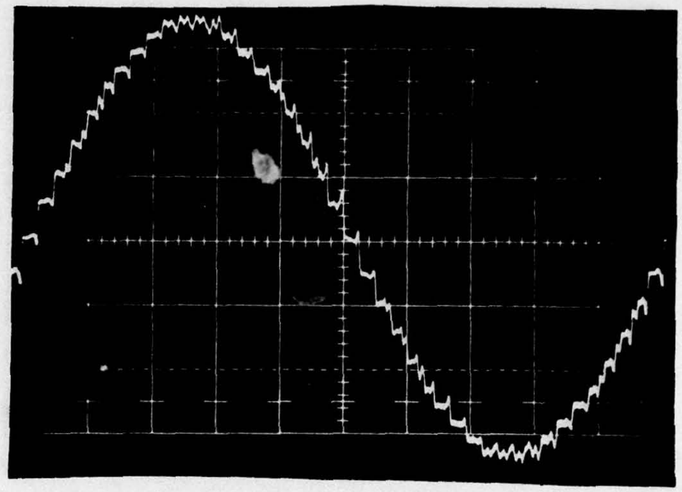
60 HZ THREE PHASE LINE-TO-NEUTRAL VOLTAGES

11KW, PF = 1.0

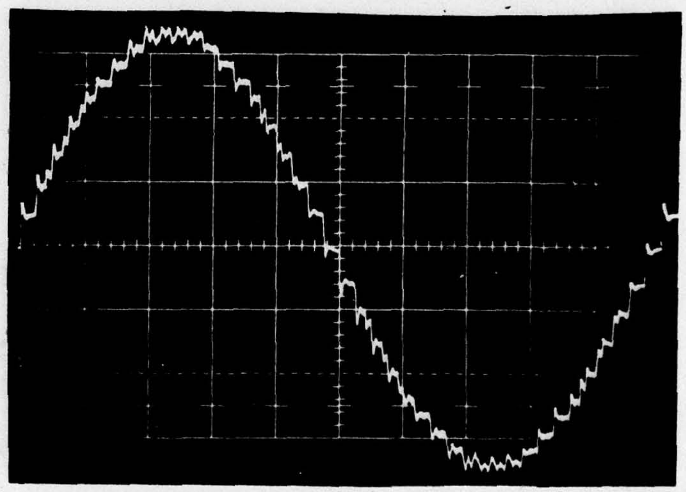
$V_{A-N}$

THD = 4.18%

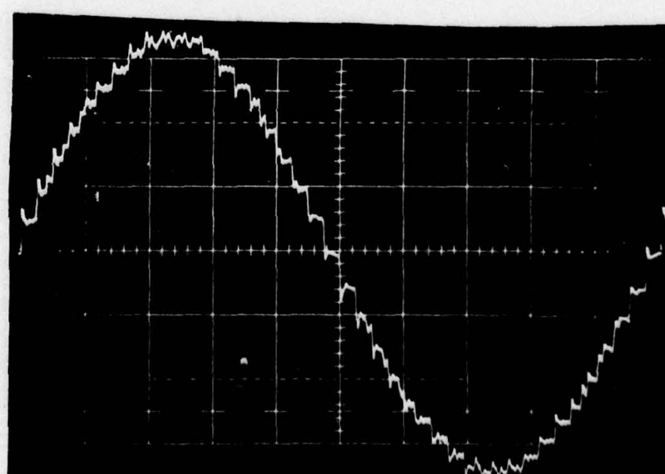


$V_{B-N}$

↕ 50 V/DIV.



$V_{C-N}$



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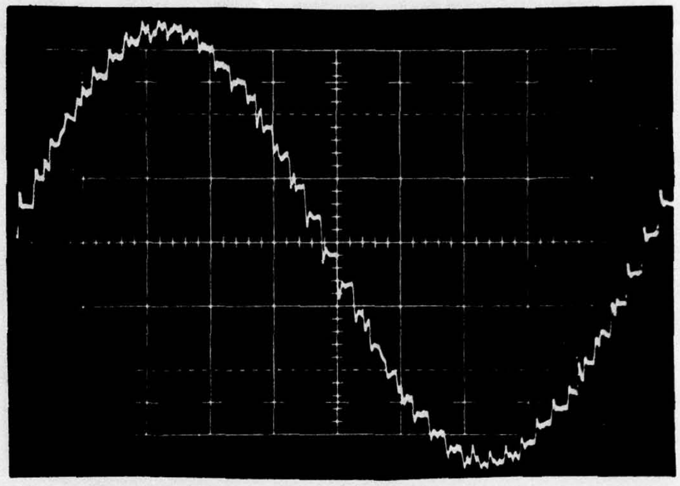
60 Hz THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

11KW, PF=0.8

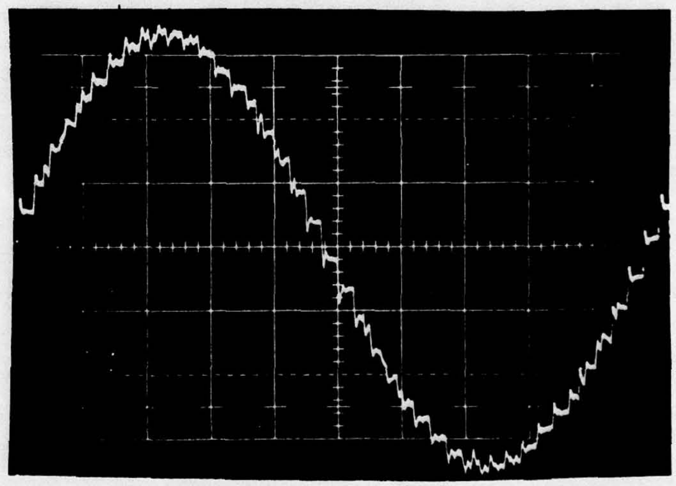
$V_{A-N}$

THD=4.33%

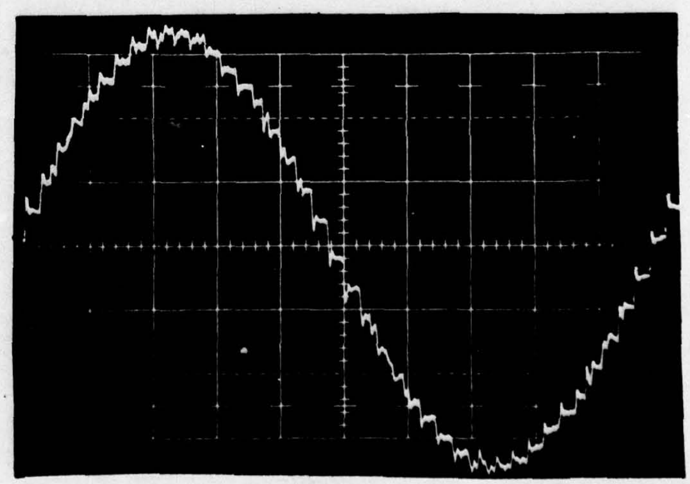


$V_{B-N}$

↕ 50V/DIV.



$V_{C-N}$



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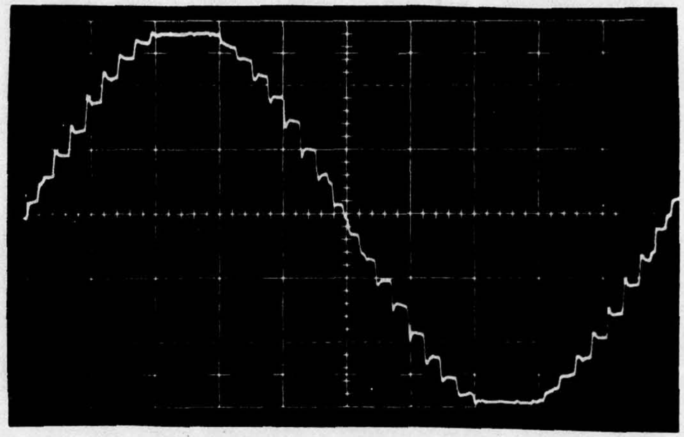
60 HZ THREE PHASE
LINE-TO-LINE VOLTAGES



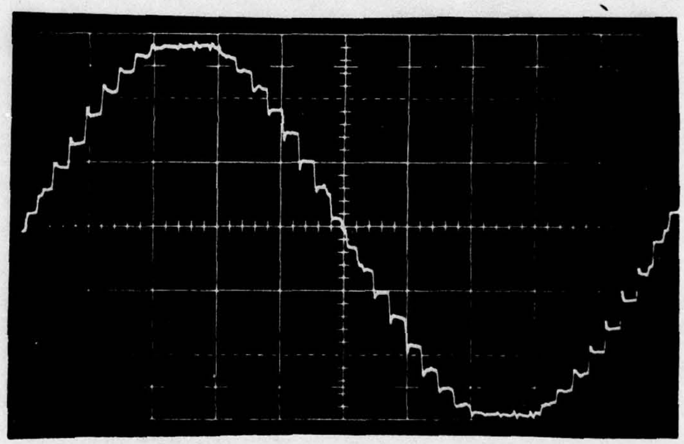
NO LOAD

$V_{A-B}$

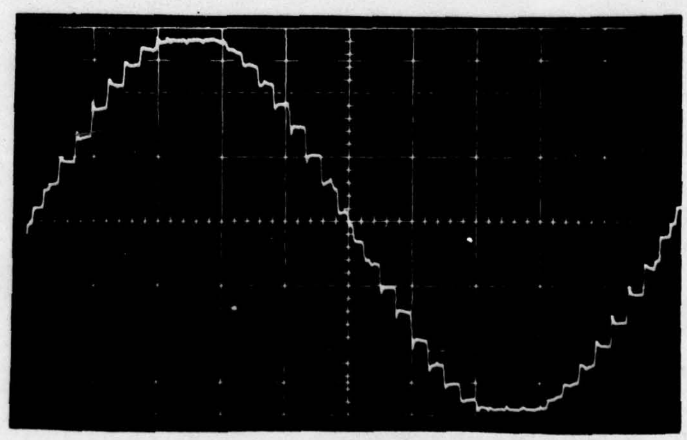
THD=4.25%

$V_{B-C}$

↕ 100V/DIV.



$V_{C-A}$



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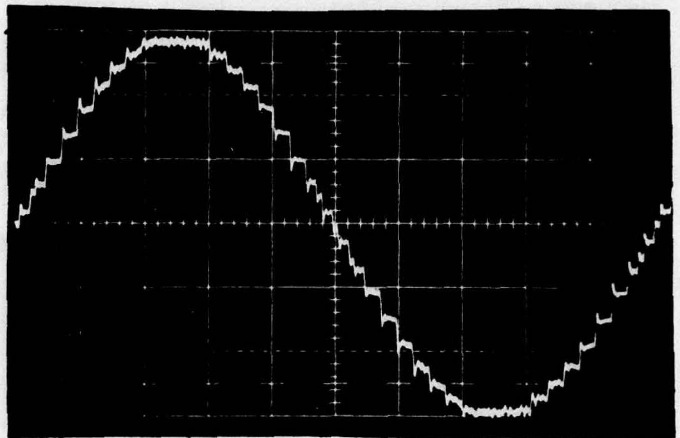
60 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

11 KW, PF = 1.0

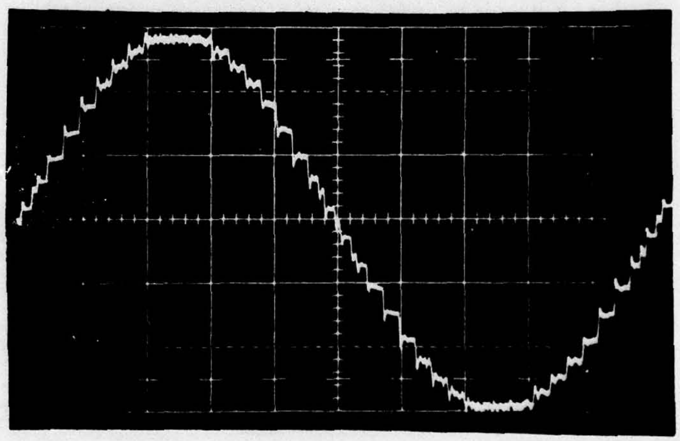
$V_{A-B}$

THD = 4.15%

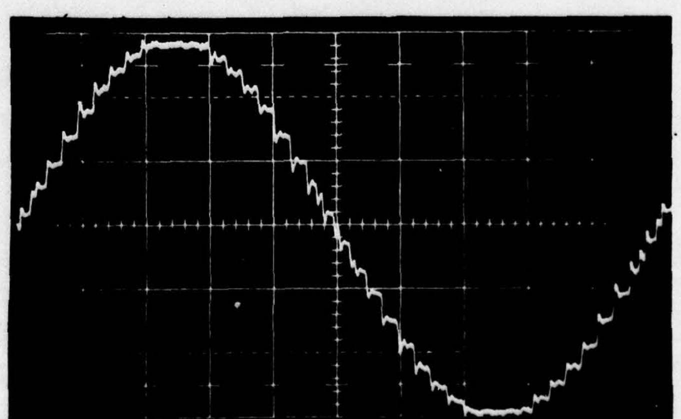


$V_{B-C}$

↕ 100V/DIV.



$V_{C-A}$



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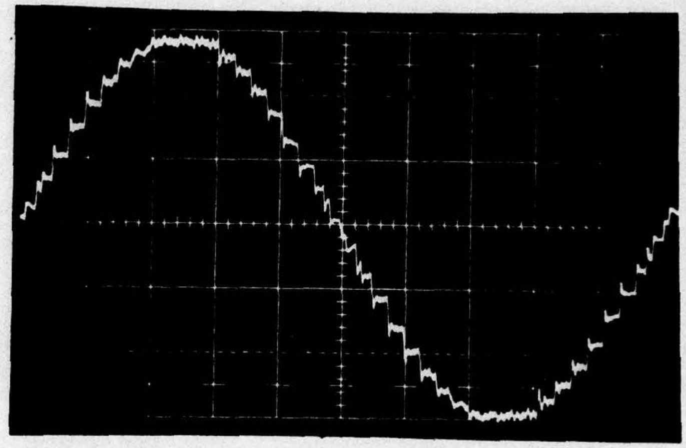
60 HZ THREE PHASE
LINE-TO-LINE VOLTAGES

11KW, PF=0.8

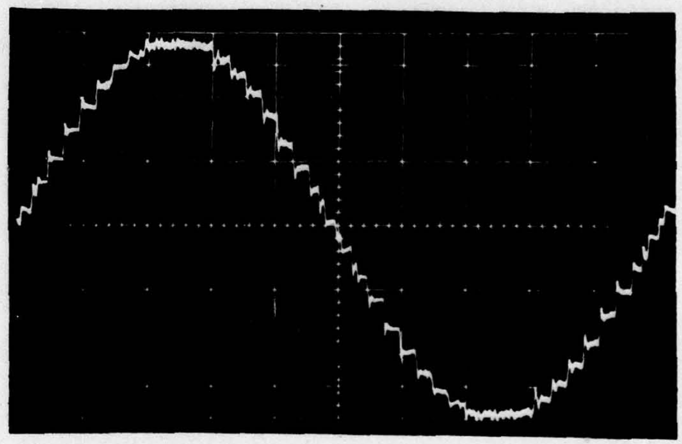
$V_{A-B}$

THD = 4.32%

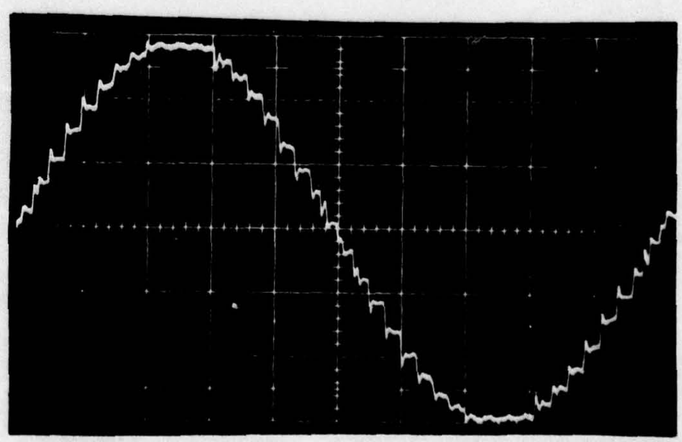


$V_{B-C}$

↕ 100V/DIV.



$V_{C-A}$



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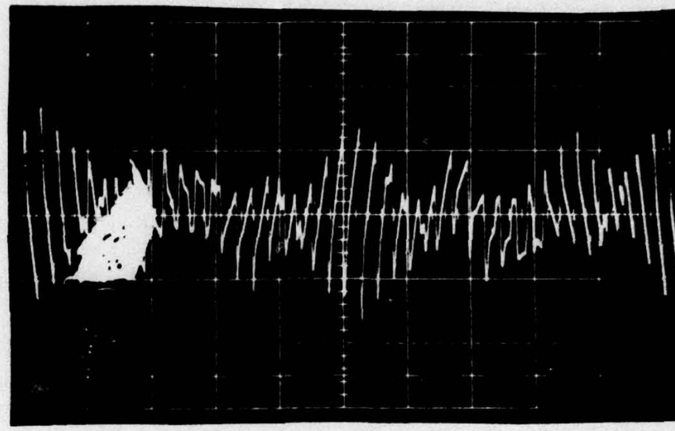
DEVIATION FACTOR

60HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

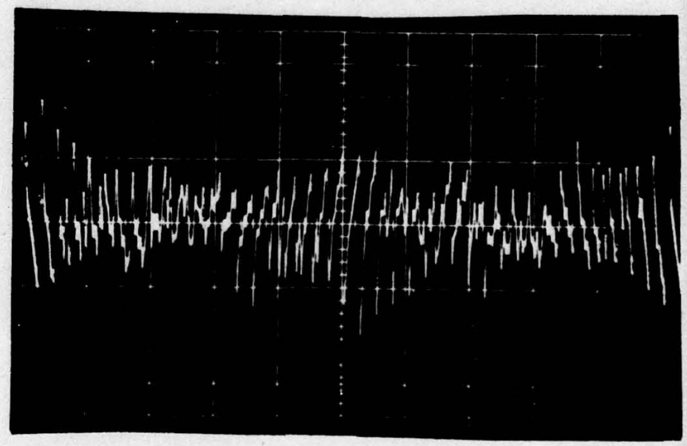
NO LOAD



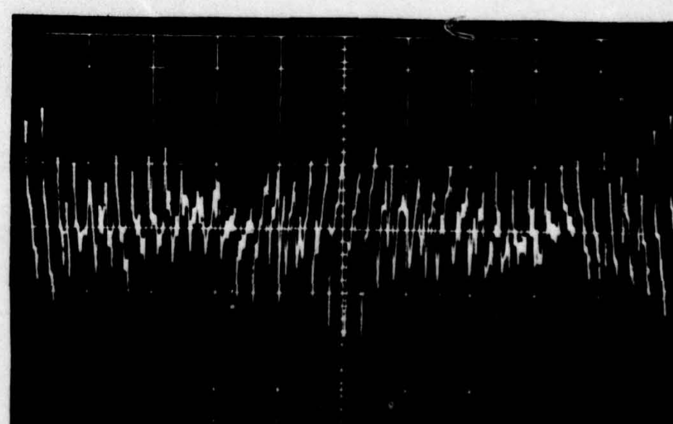
↕ 10V/DIV.

⟷ 2MS/DIV.

11KW, PF=1.0



11KW, PF=0.8



DISTRIBUTION:

## MEASUREMENTS OF INDIVIDUAL HARMONICS

400 HZ THREE PHASE NO LOAD

| HARMONIC NUMBER | FREQUENCY KHZ | PERCENT OF FUND. L-T-N | PERCENT OF FUND. L-T-L |
|---|---|---|---|
| 1 | 0.4 | 100 | 100 |
| 5 | 2.0 | 2.38 | 2.30 |
| 7 | 2.8 | 2.23 | 1.95 |
| 11 | 4.4 | 0.9 | 0.87 |
| 13 | 5.2 | 0.15 | 0.26 |
| 23 | 9.2 | — | 0.12 |
| 35 | 14.0 | 0.1 | 0.12 |
| 37 | 14.8 | 0.1 | 0.12 |
| 41 | 16.4 | 0.17 | 0.23 |
| 43 | 17.2 | 0.06 | 0.10 |
| COMPUTED THD. | | 3.38 % | 3.16% |

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## MEASUREMENTS OF INDIVIDUAL HARMONICS

400HZ THREE PHASE 11KW, PF = 1.0

| HARMONIC NUMBER | FREQUENCY KHZ | PERCENT OF FUND. L-T-N | PERCENT OF FUND. L-T-L |
|---|---|---|---|
| 1 | 0.4 | 100 | 100 |
| 3 | 1.2 | 0.3 | 0.15 |
| 5 | 2.0 | 2.4 | 2.4 |
| 7 | 2.8 | 1.8 | 1.7 |
| 11 | 4.4 | 0.67 | 0.82 |
| 13 | 5.2 | 0.41 | 0.24 |
| 19 | 7.6 | 0.12 | 0.10 |
| 21 | 8.4 | 0.09 | 0.08 |
| 23 | 9.2 | 0.22 | 0.20 |
| 25 | 10.0 | 0.17 | — |
| 31 | 12.4 | 0.08 | — |
| 35 | 14.0 | 0.13 | 0.13 |
| 37 | 14.8 | 0.15 | 0.12 |
| 41 | 16.4 | 0.27 | 0.23 |
| 43 | 17.2 | 0.1 | 0.08 |
| COMPUTED THD. | | 3.146% | 3.12% |

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MEASUREMENTS OF INDIVIDUAL HARMONICS

400HZ THREE PHASE 11KW, PF = 0.8

| HARMONIC NUMBER | FREQUENCY KHZ | PERCENT OF FUND. | |
|---|---|---|---|
| | | L-T-N | L-T-L |
| 1 | 0.4 | 100 | 100 |
| 5 | 2.0 | 1.22 | 1.15 |
| 7 | 2.8 | 1.12 | 1.02 |
| 11 | 4.4 | 0.65 | 0.80 |
| 13 | 5.2 | 0.37 | 0.23 |
| 17 | 6.8 | 0.20 | 0.18 |
| 29 | 11.6 | 0.16 | 0.10 |
| 31 | 12.4 | 0.10 | 0.10 |
| 35 | 14.0 | 0.15 | 0.13 |
| 37 | 14.8 | 0.19 | 0.15 |
| 41 | 16.4 | 0.24 | 0.20 |
| COMPUTED THD. | | 1.86 % | 1.78 % |

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MEASUREMENTS OF INDIVIDUAL HARMONICS

60HZ THREE PHASE NO LOAD

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND. L-T-N | PERCENT OF FUND. L-T-L |
|---|---|---|---|
| 5 | 300 | 0.98 | 0.94 |
| 7 | 420 | 1.10 | 1.10 |
| 11 | 660 | 0.70 | 0.65 |
| 13 | 780 | 0.20 | 0.20 |
| 17 | 1020 | 0.28 | 0.29 |
| 19 | 1140 | 0.15 | 0.14 |
| 25 | 1500 | 0.20 | — |
| 35 | 2100 | 0.56 | 0.54 |
| 37 | 2220 | 1.60 | 1.60 |
| 41 | 2460 | 2.70 | 2.65 |
| 43 | 2580 | 1.35 | 1.30 |
| 47 | 2820 | .24 | .28 |
| 53 | 3180 | .11 | .15 |
| 71 | 4260 | .16 | .15 |
| 77 | 4620 | .95 | .95 |
| 79 | 4740 | 1.20 | 1.18 |
| 83 | 4980 | .98 | .96 |
| 85 | 5100 | .16 | .18 |
| 113 | 6780 | — | 0.20 |
| 119 | 7140 | — | 1.00 |
| 121 | 7260 | 0.57 | 0.65 |
| 157 | 9420 | — | 0.25 |
| 161 | 9660 | — | 0.54 |
| 163 | 9780 | 0.20 | 0.26 |
| COMPUTED THD | | 4.32% | 4.61% |

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## MEASUREMENTS OF INDIVIDUAL HARMONICS

60HZ THREE PHASE 11KW, PF=1.0

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND. L-T-N | PERCENT OF FUND. L-T-L |
|---|---|---|---|
| 5 | 300 | 0.52 | 0.51 |
| 7 | 420 | 0.38 | 0.40 |
| 11 | 650 | 0.70 | 0.70 |
| 13 | 780 | 0.20 | 0.18 |
| 17 | 1020 | 0.30 | 0.28 |
| 19 | 1140 | 0.18 | 0.16 |
| 23 | 1380 | 0.12 | 0.13 |
| 25 | 1500 | 0.27 | 0.26 |
| 29 | 1740 | 0.36 | 0.35 |
| 31 | 1860 | 0.32 | 0.33 |
| 35 | 2100 | 0.23 | 0.24 |
| 37 | 2220 | 1.00 | 0.96 |
| 41 | 2460 | 2.40 | 2.35 |
| 43 | 2580 | 1.45 | 1.40 |
| 71 | 4260 | 0.26 | 0.25 |
| 73 | 4360 | 0.26 | 0.22 |
| 77 | 4620 | 1.10 | 1.00 |
| 79 | 4740 | 1.65 | 1.46 |
| 83 | 4480 | 0.91 | 0.88 |
| 101 | 6060 | — | 0.20 |
| 109 | 6540 | 0.22 | 0.22 |
| 113 | 6780 | — | 0.23 |
| 119 | 7140 | 1.35 | 1.50 |
| 121 | 7260 | 0.64 | 0.86 |
| 125 | 7500 | 0.20 | 0.23 |
| 154 | 9240 | 0.60 | — |
| 156 | 9360 | 0.44 | 0.60 |
| COMPUTED THD. | | 4.25% | 4.16% |

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MEASUREMENTS OF INDIVIDUAL HARMONICS

60HZ THREE PHASE 11KW, PF= 0.8

| HARMONIC NUMBER | FREQUENCY HZ | PERCENT OF FUND. | |
|---|---|---|---|
| | | L-T-N | L-T-L |
| 1 | 60 | 100 | 100 |
| 5 | 300 | 0.46 | 0.45 |
| 7 | 420 | 0.47 | 0.45 |
| 11 | 660 | 0.56 | 0.58 |
| 13 | 780 | 0.26 | 0.27 |
| 17 | 1020 | 0.57 | 0.57 |
| 19 | 1140 | 0.25 | 0.25 |
| 25 | 1500 | 0.42 | 0.40 |
| 29 | 1740 | 0.26 | 0.34 |
| 31 | 1860 | 0.26 | 0.26 |
| 35 | 2100 | 0.32 | 0.31 |
| 37 | 2220 | 1.20 | 1.30 |
| 41 | 2460 | 2.50 | 2.50 |
| 43 | 2580 | 1.40 | 1.40 |
| 44 | 2640 | — | 0.24 |
| 51 | 3060 | .26 | — |
| 53 | 3180 | — | .21 |
| 71 | 4620 | — | 1.25 |
| 79 | 4740 | — | 1.40 |
| 83 | 4980 | 1.54 | — |
| 119 | 7140 | 1.40 | 1.60 |
| COMPUTED THD. | | 3.95% | 4.21% |

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## DC VOLTAGE COMPONENT

| VAN Vrms | VBN Vrms | VCN Vrms | VAN DC mV | VBN DC mV | VCN DC mV | IA A rms | IB A rms | IC A rms | FREQ. Hz | LOAD KW | P.F. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 120.1 | 119.7 | 120.0 | +25 | +50 | +40 | 0 | 0 | 0 | 400 | 0 | 1 |
| 120.2 | 119.9 | 120.2 | +23 | +50 | +36 | 30.77 | 30.42 | 31.58 | 400 | 11 | 1.0 |
| 119.8 | 119.2 | 119.7 | ±50 | ±14 | +10 | 39.13 | 39.86 | 39.97 | 400 | 11 | 0.8 |
| 120.26 | 120.28 | 119.76 | +5 | -3 | -6 | 0 | 0 | 0 | 60 | 0 | 1 |
| 120.21 | 120.31 | 119.7 | +5 | +4 | -13 | 30.74 | 30.96 | 31.65 | 60 | 11 | 1.0 |
| 120.21 | 120.11 | 119.71 | +7 | +4 | +3 | 39.0 | 39.5 | 39.8 | 60 | 11 | 0.8 |

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3.24.1.4 PHASE VOLTAGE BALANCE

| $V_{AN}$ Vrms | $V_{BN}$ Vrms | $V_{CN}$ Vrms | $V_{AB}$ Vrms | $V_{BC}$ Vrms | $V_{CA}$ Vrms | $I_A$ A rms | $I_B$ A rms | $I_C$ Arms | FREQ. HZ | LOAD KW | P.F. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 120.1 | 119.7 | 119.9 | 207.5 | 207.4 | 208.3 | 0 | 0 | 0 | 400 | 0 | — |
| 120.3 | 119.8 | 120.1 | 207.5 | 208.1 | 208.5 | 30.77 | 30.91 | 31.58 | 400 | 11 | 1.0 |
| 120.0 | 119.3 | 119.8 | 207.1 | 207.4 | 207.6 | 39.13 | 39.87 | 39.98 | 400 | 11 | 0.8 |
| 120.27 | 120.27 | 119.78 | 208.2 | 207.6 | 207.9 | 0 | 0 | 0 | 60 | 0 | 0 |
| 120.20 | 120.30 | 119.8 | 208.0 | 208.0 | 207.7 | 30.74 | 30.95 | 31.6 | 60 | 11 | 1.0 |
| 120.20 | 120.10 | 119.70 | 208.0 | 208.0 | 208.0 | 38.69 | 39.6 | 39.8 | 60 | 11 | 0.8 |

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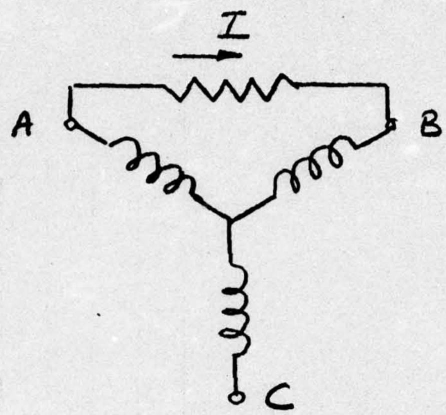
3.24.1.5 EFFECT OF UNBALANCED LOAD (3PHASE)




| | 400 HZ | 60 HZ |
|---|---|---|
| | I = 8.73 A. rms | I = 8.7 A rms |
| $V_{AB}$ | 207.7 | 206.6 |
| $V_{BC}$ | 211.4 | 220.5 |
| $V_{CA}$ | 212.8 | 218.1 |
| $V_{AN}$ | 121.3 | 121.2 |
| $V_{BN}$ | 117.5 | 122.7 |
| $V_{CN}$ | 121.5 | 128.9 |
| MAX. L-T-L VOLTAGE DIFFERENCE | 5.1 | 13.9 |

$\frac{5.1}{208} \times 100 = \underline{\underline{2.45\%}}$

$\frac{13.9}{208} \times 100 = \underline{\underline{6.68\%}}$

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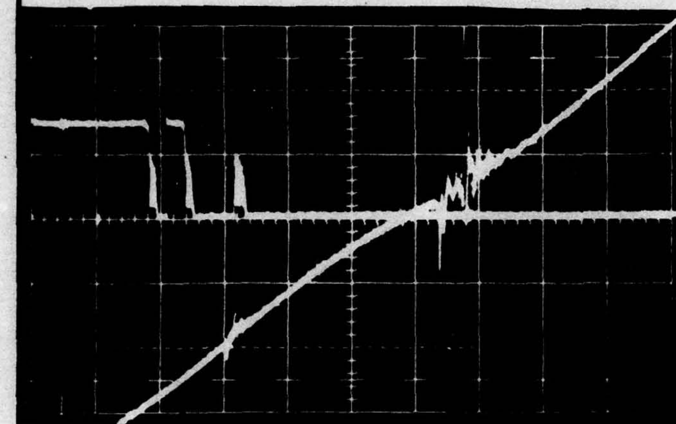
3.24.1.6 <u>PHASE ANGLE BALLANCE</u>

400 HZ BALANCED LOAD <u>NO LOAD</u>

L-T-N VOLTAGES



PHASE A

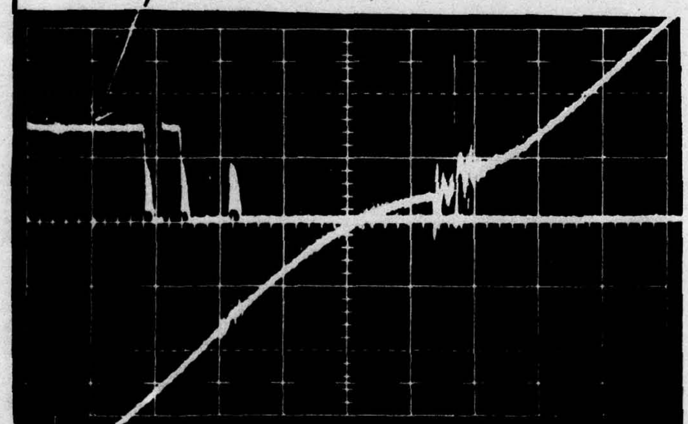
0 CROSS-OVER

↕ 5V/DIV.

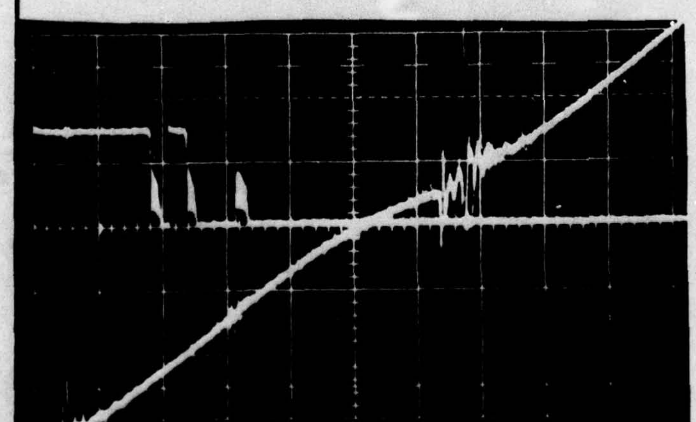
↔ 1.44°/DIV.

(10 μ SEC/DIV.)

REFERENCE MARKER



PHASE B



PHASE C

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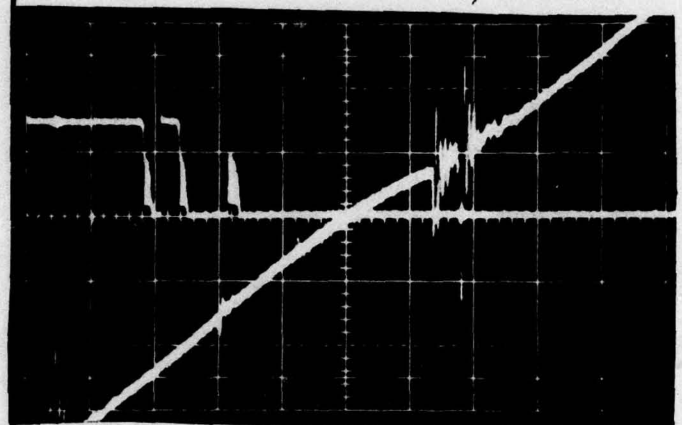
400 HZ BALANCED LOAD
L-T-N VOLTAGES

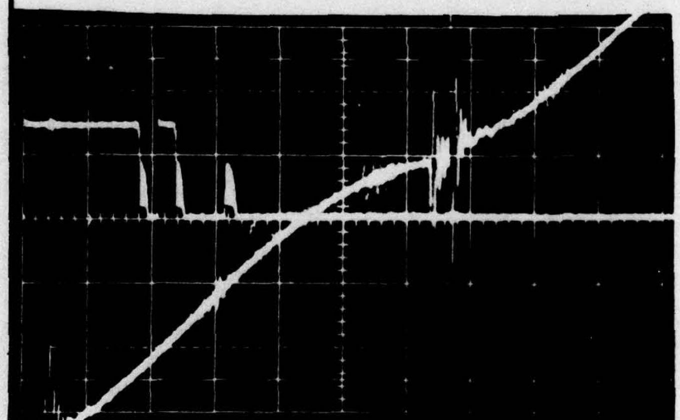
11KW, PF = 1.0



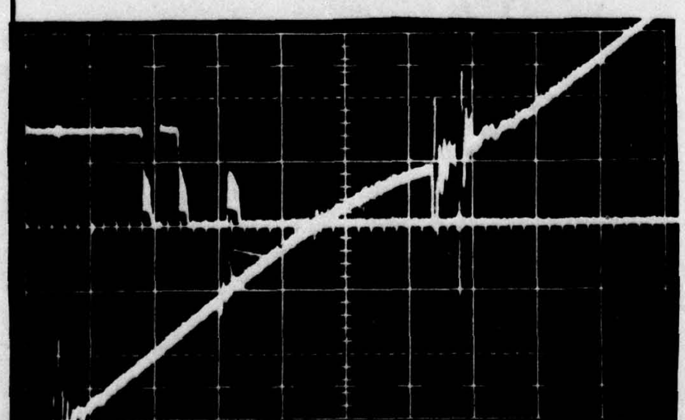
PHASE A

↕ 5V/DIV.

↔ 1.44°/DIV.



PHASE B



PHASE C

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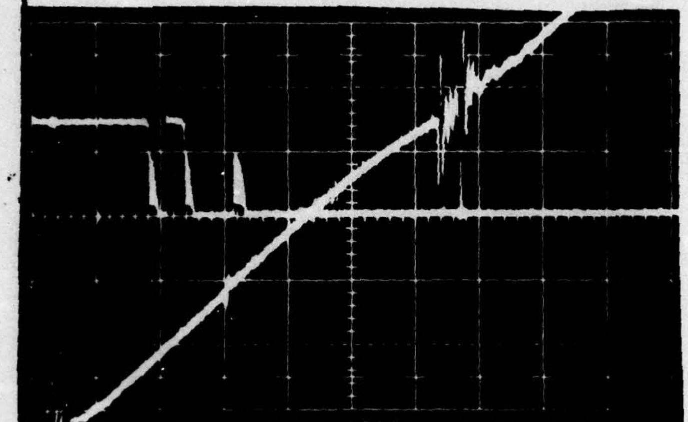
400 HZ BALANCED LOAD
L-T-N VOLTAGES

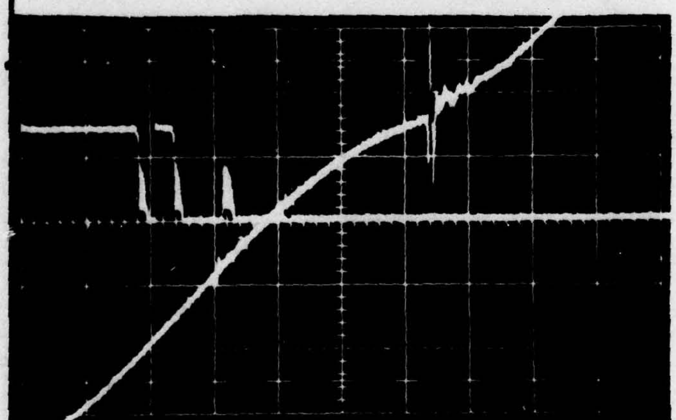
11KW, PF = 0.8



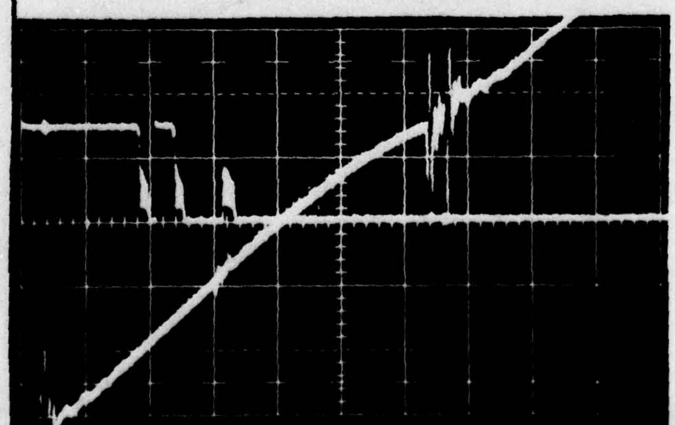
PHASE A

↕ 5V/DIV.

↔ 1.44°/DIV.



PHASE B



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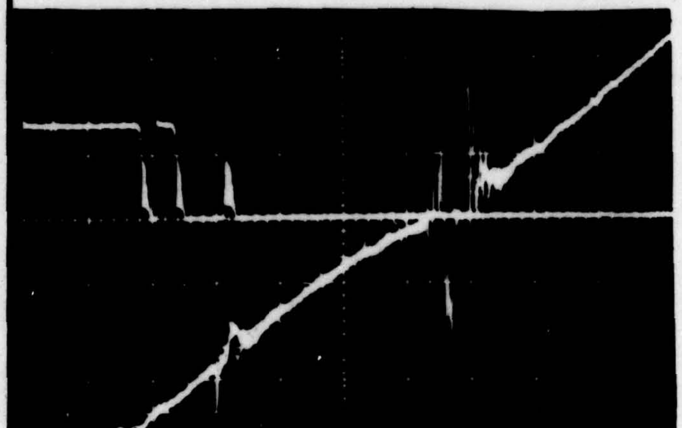
400 HZ 25 PERCENT UNBALANCED LOAD
AS DESCRIBED IN 3.24.1.5

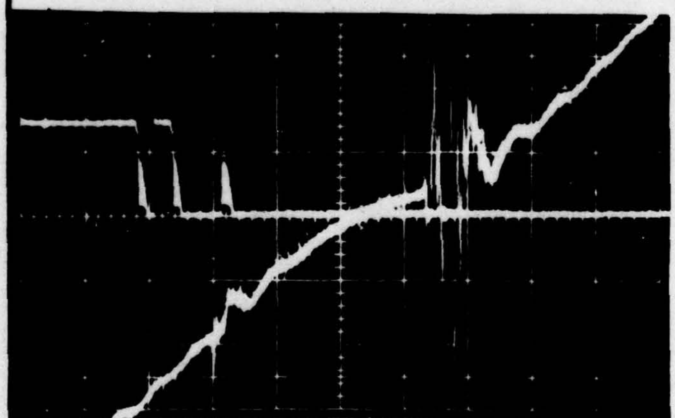
L-T-N VOLTAGES



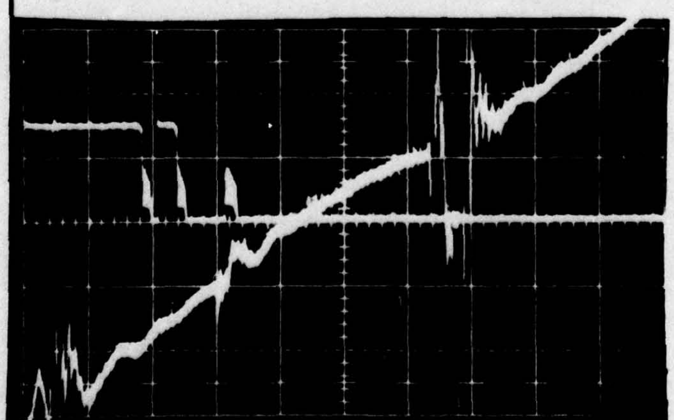
PHASE A

↕ 5V/DIV.

↔ 1.44°/DIV.



PHASE B



PHASE C

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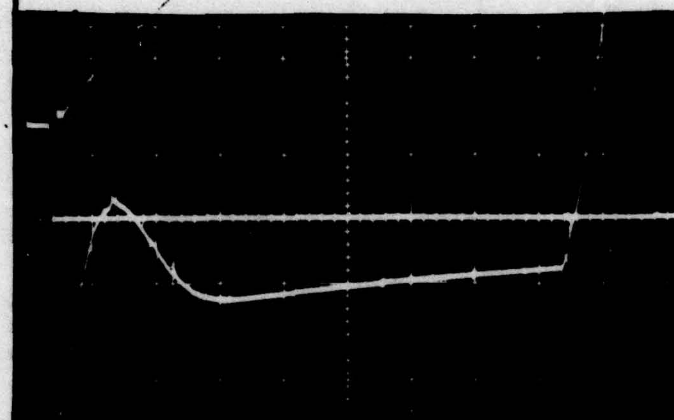
60 HZ BALANCED LOAD
L-T-N VOLTAGES

NO LOAD

REFERENCE MARKER

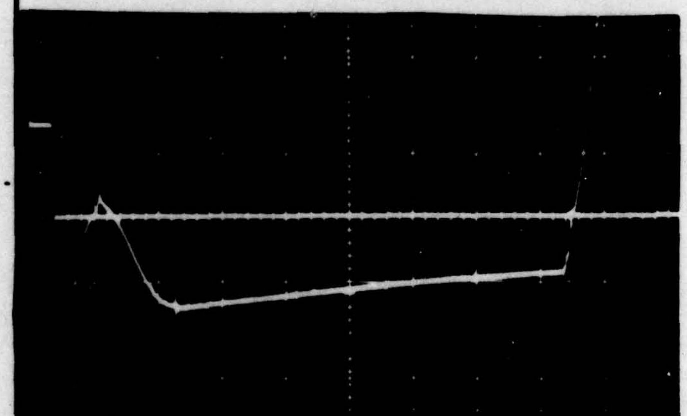


PHASE A

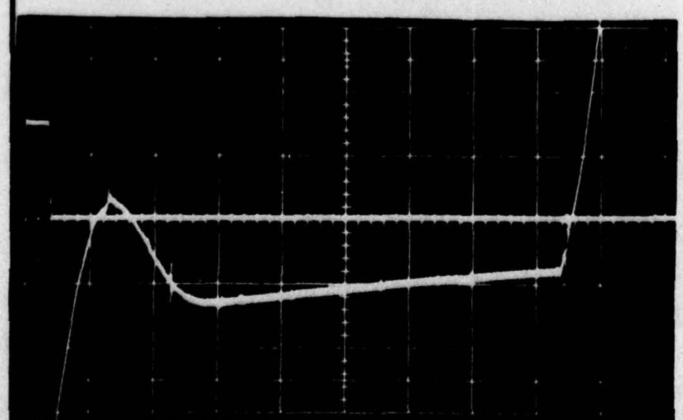
—0 CROSS-OVER

↕ 5V/DIV.

↔ 1.09°/DIV.
(50 μSEC/DIV.)



PHASE B



PHASE C

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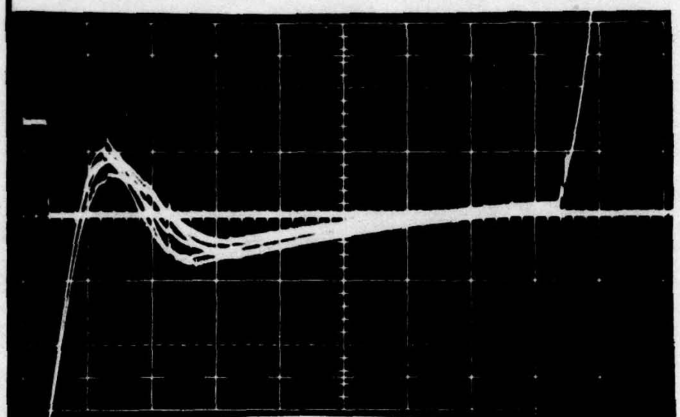
60HZ BALANCED LOAD
L-T-N VOLTAGES

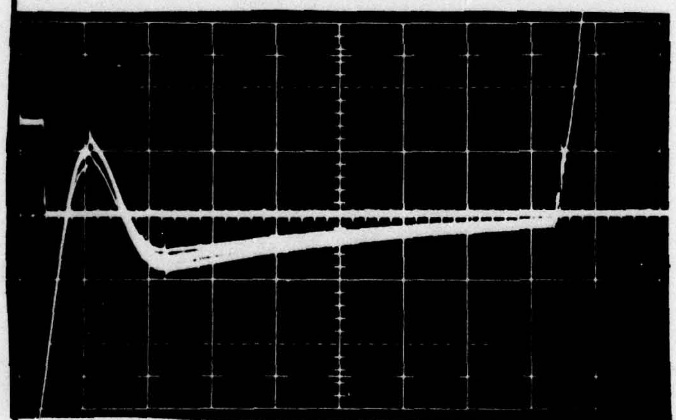
11KW, PF = 1.0



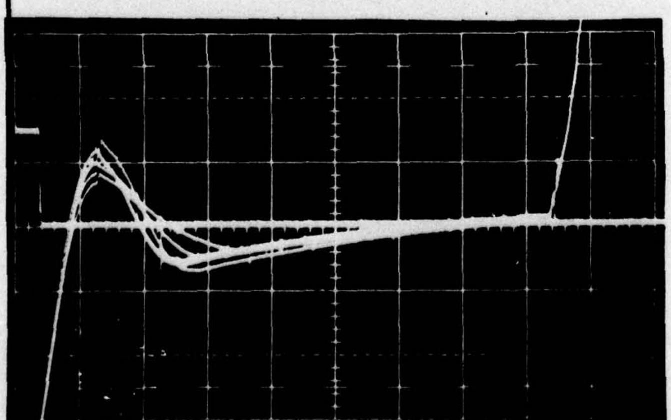
PHASE A

↕ 5V/DIV.

↔ 1.09%/DIV.



PHASE B



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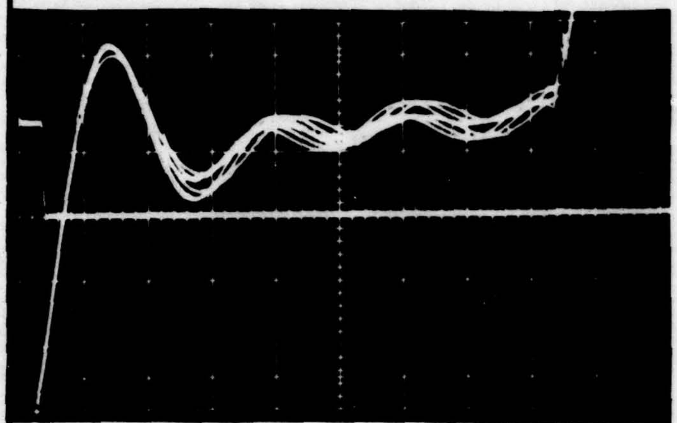
60HZ BALANCED LOAD
L-T-N VOLTAGES

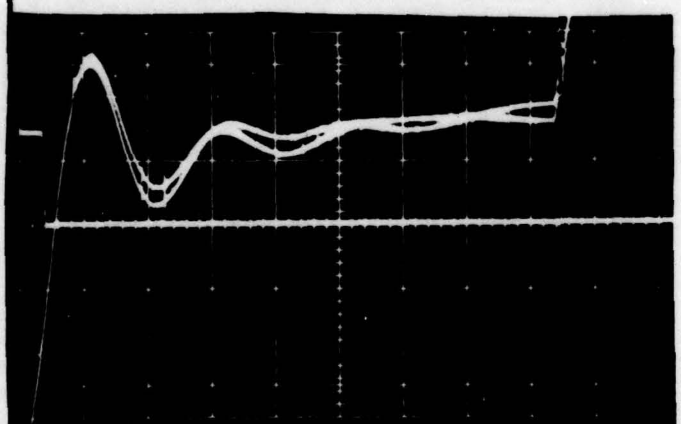
11KW, PF=0.8



PHASE A

↕ 5V/DIV.

↔ 1.09°/DIV.



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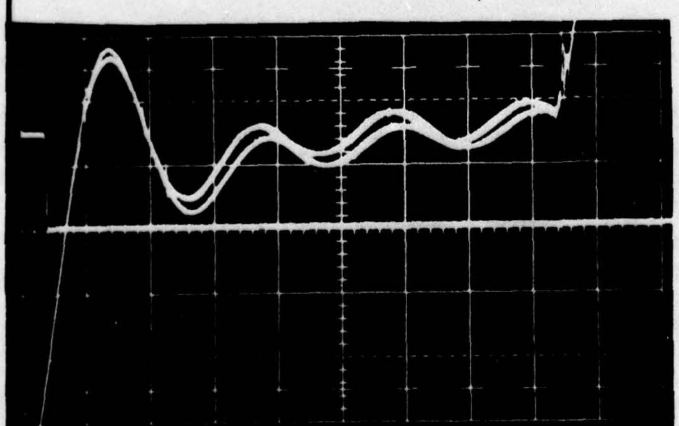

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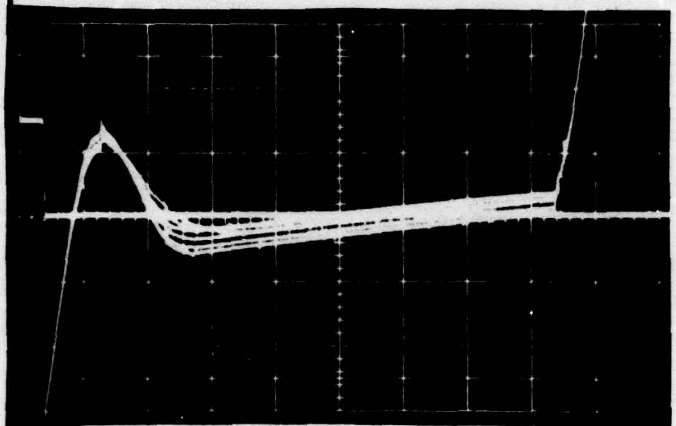
60HZ 25 PERCENT UNBALANCED LOAD
AS DESCRIBED IN 3.24.1.5

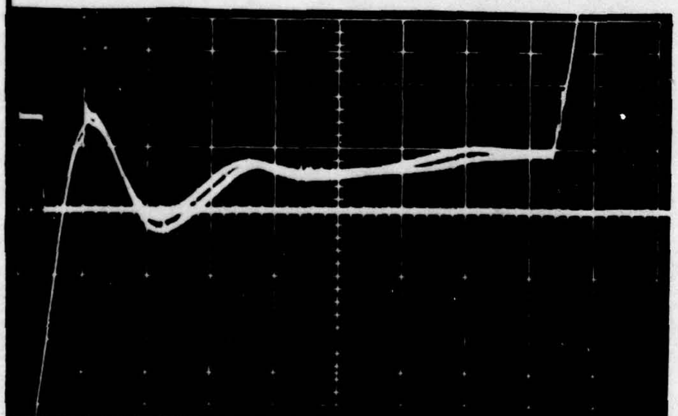


L-T-N VOLTAGES

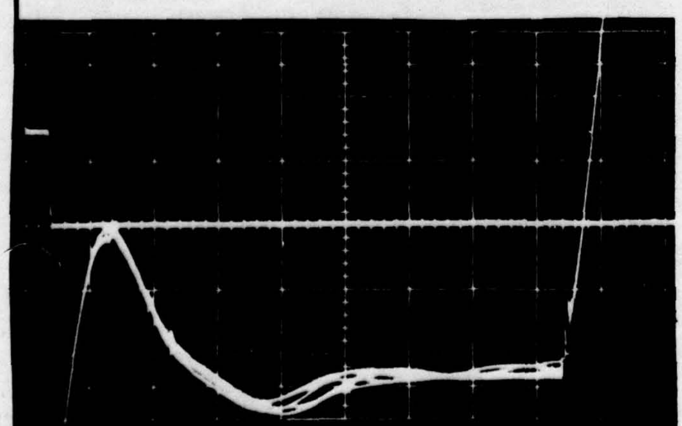
PHASE A

↕ 50V/DIV.

↔ 1.09°/DIV.



PHASE B



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| | | | APPROVED | |

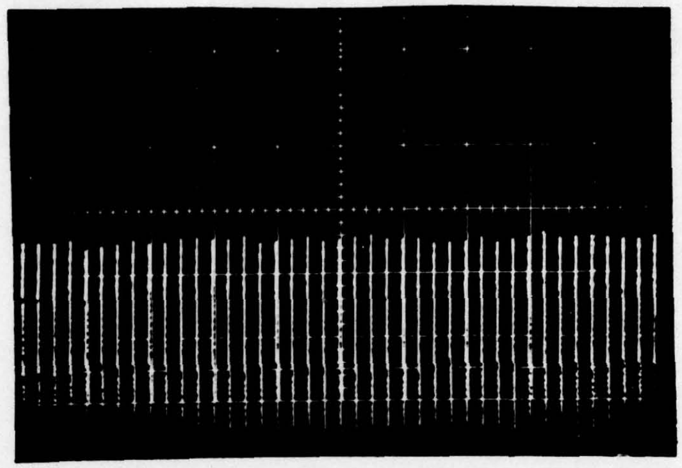
3.24.1.7 VOLTAGE MODULATION

400 HZ THREE PHASE
L-T-N VA-N

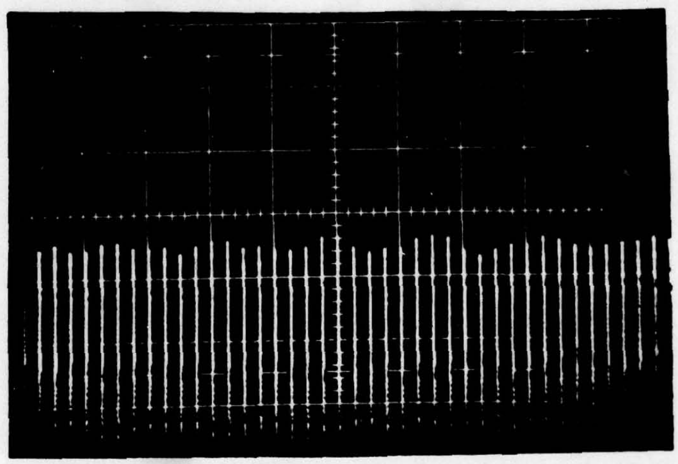
NO LOAD

↕ 2V/DIV.

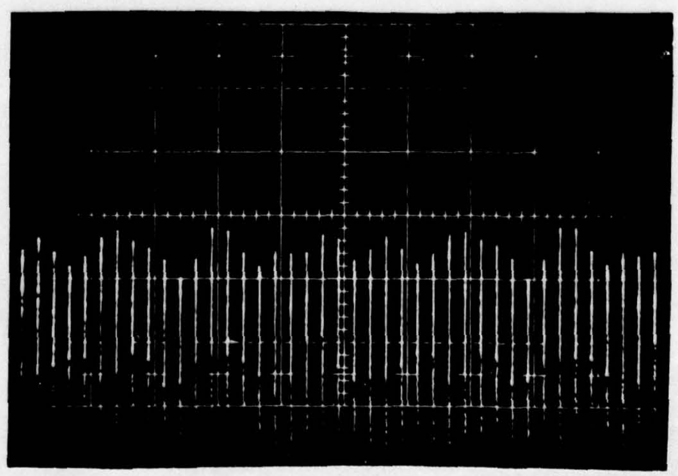
↔ 10mS/DIV.



11KW, PF= 1.0



11KW, PF= 0.8



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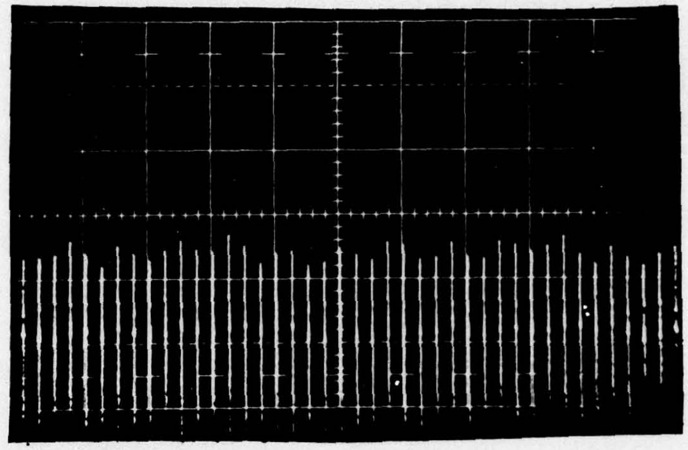
400 HZ THREE PHASE
L-T-L $V_{A-B}$

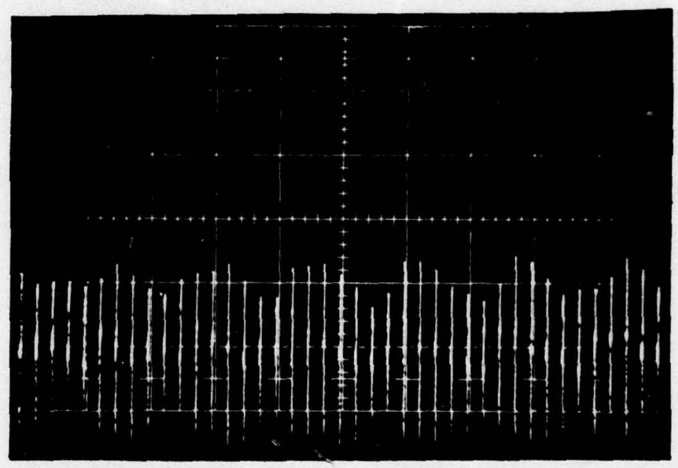
NO LOAD

↕ 2V/DIV.

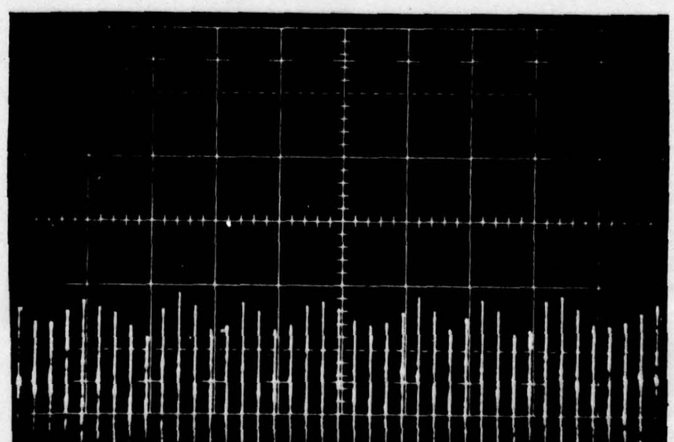
⟷ 10MS/DIV.



11KW, PF=1.0



11KW, PF=0.8



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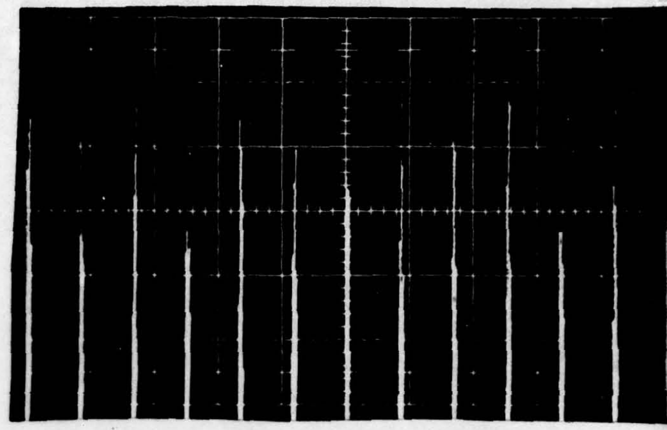
60 Hz THREE PHASE
L-T-L VA-B

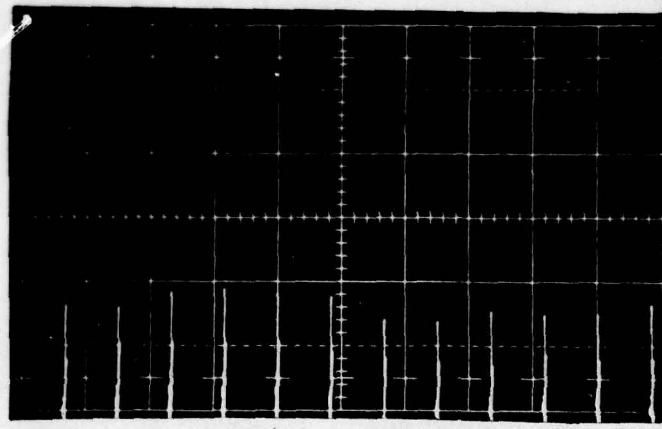
NO LOAD

↕ 2V/DIV.

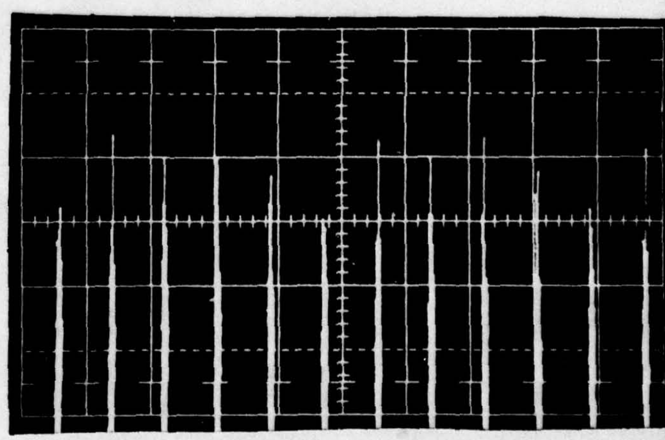
↔ 20 ms/DIV.



11KW, PF = 1.0



11KW, PF = 0.8



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VOLTAGE MODULATION - CONVERTER OUTPUT DATA

| FREQ. HZ | $V_{AN}$ VRMS | $V_{BN}$ VRMS | $V_{CN}$ VRMS | $V_{AB}$ VRMS | $V_{BC}$ VRMS | $V_{CA}$ VRMS | $I_A$ ARMS | $I_B$ ARMS | $I_C$ ARMS | LOAD KW | P.F. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 119.8 | 119.7 | 119.9 | 206.8 | 207.6 | 206.8 | — | — | — | — | — |
| 400 | 119.8 | 119.7 | 119.9 | 206.8 | 207.9 | 207.5 | 30.8 | 30.8 | 31.5 | 11KW | 1.0 |
| 400 | 119.8 | 119.6 | 119.8 | 206.3 | 206.9 | 206.9 | 34.0 | 39.8 | 39.9 | 11KW | 0.8 |
| 60 | 120.0 | 120.1 | 120.1 | 208.1 | 208.1 | 208.1 | — | — | — | — | — |
| 60 | 120.1 | 120.1 | 120.0 | 208 | 207.9 | 207.8 | 30.74 | 30.96 | 31.60 | 11KW | 1.0 |
| 60 | 120.2 | 120.1 | 119.7 | 208 | 207.9 | 707.9 | 39.1 | 39.2 | 39.5 | 11KW | 0.8 |

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3.24.1.8 VOLTAGE REGULATION

3.24.2.2 FREQUENCY REGULATION

| LOAD | PF | $V_{AN}$ $V_{RMS}$ | $V_{BN}$ $V_{RMS}$ | $V_{CN}$ $V_{RMS}$ | $I_A$ $A_{RMS}$ | $I_B$ $A_{RMS}$ | $I_C$ $A_{RMS}$ | FREQ. HZ |
|---|---|---|---|---|---|---|---|---|
| 0 | — | 120.1 | 119.7 | 119.9 | — | — | — | 400 |
| 1/4 | 0.8 | 120.1 | 119.7 | 120.1 | 7.9 | 7.99 | 8.0 | 400 |
| 1/2 | 0.8 | 119.8 | 119.3 | 119.9 | 23.6 | 23.9 | 24.0 | 400 |
| 3/4 | 0.8 | 119.8 | 119.3 | 119.9 | 31.3 | 31.8 | 32.0 | 400 |
| FULL | 0.8 | 119.8 | 119.3 | 119.9 | 39.13 | 39.87 | 39.98 | 400 |
| 0 | — | | | | — | — | — | 60 |
| 1/4 | 0.8 | 120.2 | 120.2 | 120.0 | 8.0 | 8.0 | 8.1 | 60 |
| 1/2 | 0.8 | 120.1 | 120.1 | 120.1 | 23.7 | 23.9 | 24.0 | 60 |
| 3/4 | 0.8 | 120.0 | 120.0 | 120.1 | 31.9 | 31.9 | 31.9 | 60 |
| FULL | 0.8 | 120.0 | 120.1 | 120.1 | 39.13 | 39.85 | 39.88 | 60 |

NOTE: LOADS WERE APPLIED AND DROPPED THREE TIMES

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INHERENT VOLTAGE DROOP
OF THE 10KW FREQUENCY CHANGER

400 HZ

| LINE-TO-NEUTRAL VOLTAGE (VRMS) | LOAD (KW) PF = 0.8 |
|---|---|
| 120.0 | — |
| 119.1 | 3.2 |
| 118.5 | 5.4 |
| 118.0 | 7.6 |
| 117.4 | 9.8 |
| 116.6 | 13.4 |

%REGULATION =

$$\frac{\text{N.L. VOLTAGE} - \text{F.L. VOLTAGE}}{\text{F.L. VOLTAGE}} \times 100$$

$$\frac{120-117.4}{117.4} \times 100 = \underline{\underline{2.21}}\ \%$$

60 HZ

| | |
|---|---|
| 120.0 | — |
| 118.7 | 3.2 |
| 118.25 | 5.4 |
| 117.7 | 7.6 |
| 117.5 | 9.8 |
| 116.7 | 13.4 |

$$\frac{120-117.5}{117.5} \times 100 = \underline{\underline{2.21}}\ \%$$

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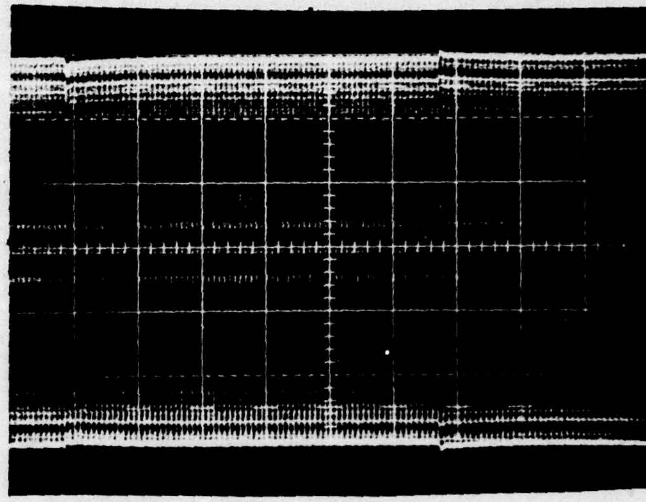
3.24.1.12 TRANSIENT VOLTAGE PERFORMANCE

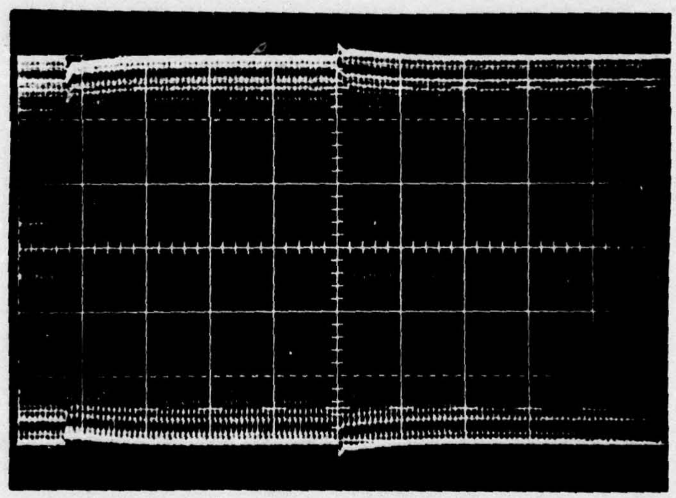
400HZ THREE PHASE
LINE-TO-NEUTRAL
VOLTAGES

1/4 LOAD, PF=0.8

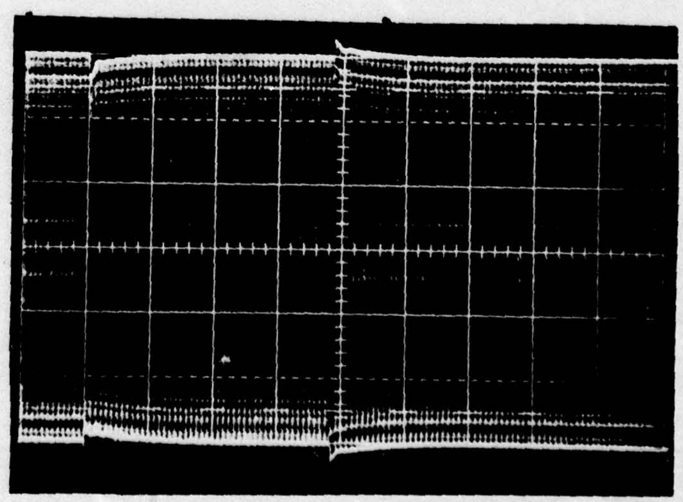
←→ 0.2SEC/DIV.



1/2 LOAD, PF=0.8



3/4 LOAD, PF=0.8



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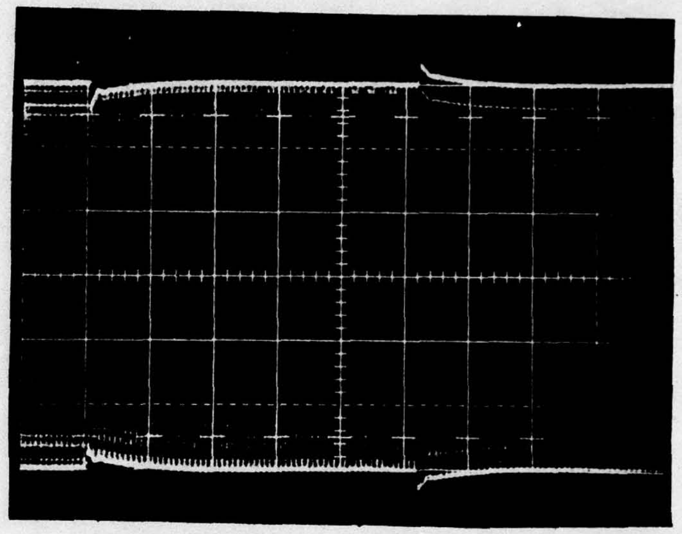
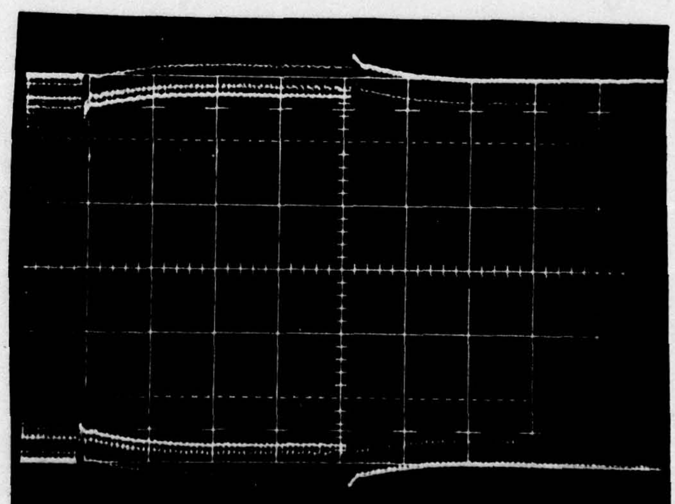
400HZ THREE PHASE
LINE-TO-NEUTRAL
VOLTAGES

FULL LOAD, PF=0.8

⟷ 0.2SEC/DIV.



2 P.U., P.F.=0.4



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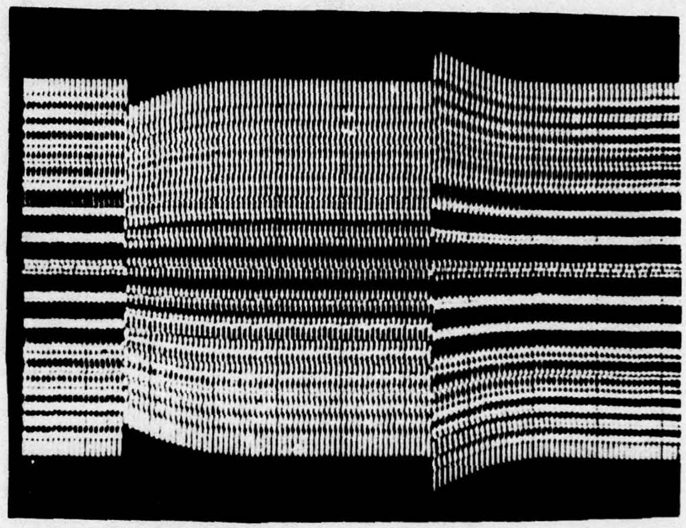
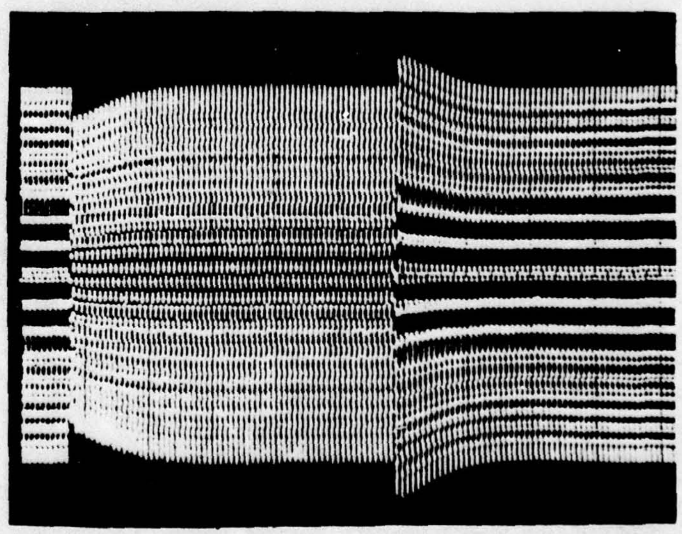
60 HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES



1/4 LOAD, PF=0.8

⟷ 0.2SEC/DIV.



1/2 LOAD, PF=0.8

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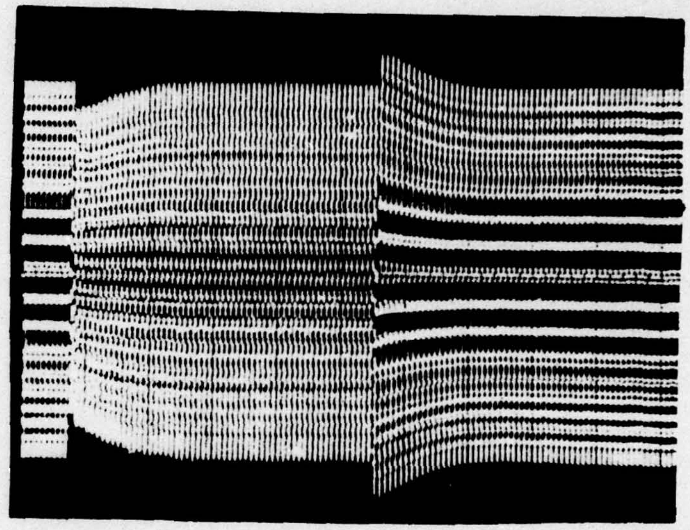
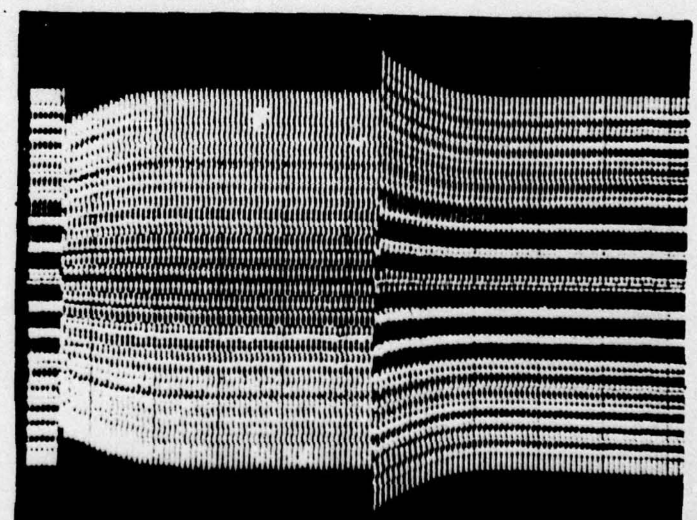
60HZ THREE PHASE
LINE-TO-NEUTRAL VOLTAGES

3/4 LOAD, PF=0.8

⟶ 0.2SEC/DIV.



FULL LOAD, PF=0.8



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400 HZ TRANSIENT PERFORMANCE

| | $V_{AN}$ $V_{RMS}$ | $V_{BN}$ $V_{RMS}$ | $V_{CN}$ $V_{RMS}$ | $I_A$ $A_{RMS}$ | $I_B$ $A_{RMS}$ | $I_C$ $A_{RMS}$ | FREQ. HZ | LOAD | PF |
|---|---|---|---|---|---|---|---|---|---|
| BEFORE LOAD STEP | 120.1 | 119.8 | 120.0 | 0 | 0 | 0 | 400 | — | 1 |
| AFTER LOAD STEP | 119.8 | 119.2 | 119.7 | 39.1 | 39.8 | 39.9 | 400 | 1 P.U. | 0.8 |
| BEFORE LOAD STEP | 120.1 | 119.8 | 120.0 | 0 | 0 | 0 | 400 | — | 1 |
| AFTER LOAD STEP | 118.7 | 117.9 | 118.4 | 66.9 | 67.9 | 67.3 | 400 | 2 P.U. | 0.48 |
| | | | | | | | | | |

NOTE: EACH LOAD APPLIED AND REMOVED THREE TIMES

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3.24.1.13 SHORT CIRCUIT

MAXIMUM CURRENT LIMITING CAPABILITIES OF THE PRESENT FREQUENCY CONVERTER BREADBOARD IN THE SHORT CIRCUIT MODE OF OPERATION.

| SHORT CIRCUIT | | FREQ. HZ | LINE CURRENT AMPS RMS |
|---|---|---|---|
| THREE PHASE L-T-N | A-N B-N C-N | 400 | 100 |
| TWO PHASE L-T-N | A-N B-N | 400 | 30 |
| ONE PHASE L-T-N | A-N | 400 | 38 |
| THREE PHASE L-T-L | A-B-C | 400 | 100 |
| ONE PHASE L-T-L | A-B | 400 | 38 |
| THREE PHASE L-T-N | A-N B-N C-N | 60 | 100 |
| TWO PHASE L-T-N | A-N B-N | 60 | 110 |
| ONE PHASE L-T-N | A-N | 60 | 120 |
| THREE PHASE L-T-L | A-B-C | 60 | 100 |
| ONE PHASE L-T-L | A-B | 60 | 55 |

DISTRIBUTION:

3.24.3 EFFICIENCY

| CIRCUIT DESCRIPTION | FREQ. HZ | INPUT POWER WATTS | OUTPUT POWER WATTS | P.F. | LOSSES WATTS | EFF.# % |
|---|---|---|---|---|---|---|
| P.F. CORRECTED 60MFD. L-T-L | 400 | 1532 | NO LOAD | — | 1532 | — |
| | 400 | 3779 | 2221 | 1.0 | 1558 | 58.8 |
| | 400 | 12854 | 11088 | 1.0 | 1766 | 86.3 |
| | 400 | 12714 | 11088 | 0.8 | 1626 | 87.2 |
| WITH STEP TRANSISTORS- NO OUTPUT CAP. | 400 | 310 | NO LOAD | — | 310 | — |
| | 400 | 2579 | 2221 | 1.0 | 358 | 86.1 |
| | 400 | 11901 | 11106 | 1.0 | 795 | 93.3 |
| | 400 | 12677 | 11106 | 0.8 | 1571 | 87.6 |

# DOES NOT INCLUDE RECTIFIER OR OTHER FIXED LOSSES.

3.24.3 EFFICIENCY

| CIRCUIT DESCRIPTION | FREQ. HZ | INPUT POWER WATTS | OUTPUT POWER WATTS | P.F. | LOSSES WATTS | EFF.# % |
|---|---|---|---|---|---|---|
| WITH STEP TRANSISTORS 60MFD L-T-N | 60 | 142 | — | — | 142 | — |
| | 60 | 2452 | 2218 | 1.0 | 234 | 90.43 |
| | 60 | 11505 | 11038 | 1.0 | 467 | 95.9 |
| ↓ | 60 | 12101 | 11038 | 0.8 | 1063 | 91.2 |

# DOES NOT INCLUDE RECTIFIER OR OTHER FIXED LOSSES

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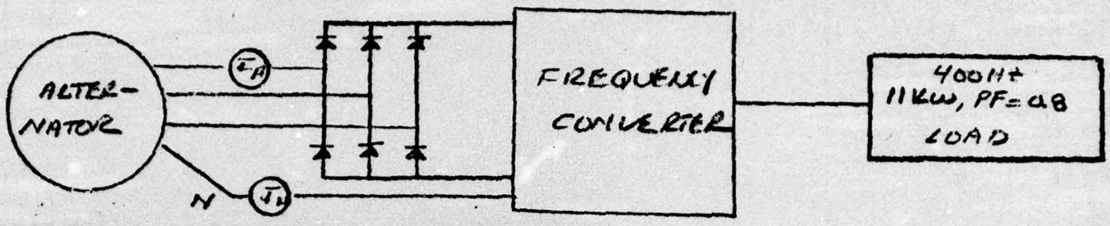
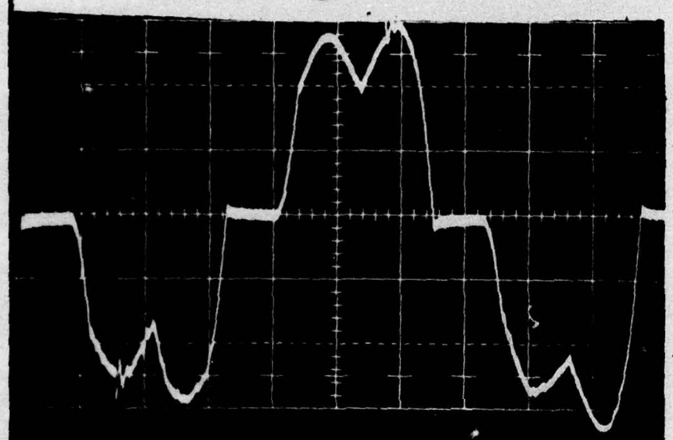
## TURBO-ALTERNATOR CURRENT WAVEFORMS INTO THE 10KW FREQUENCY CONVERTER

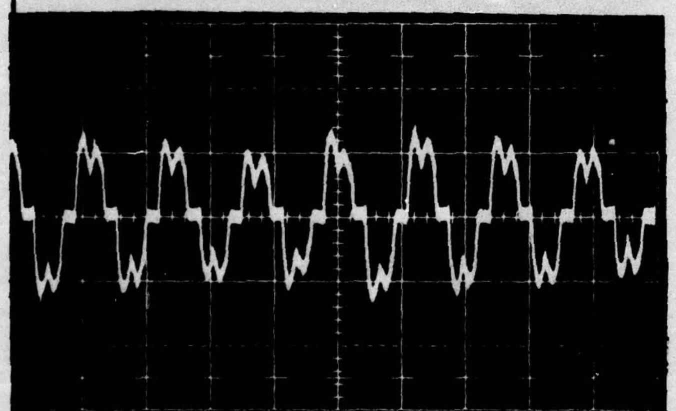


ALTERNATOR LINE CURRENT

↕ 20A/DIV.

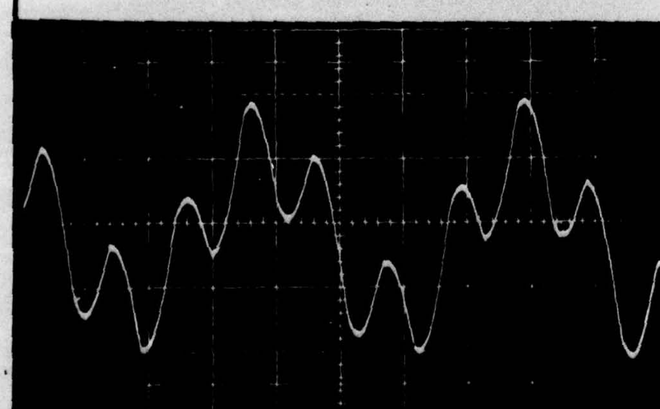
⟷ 100 μSEC/DIV.



ALTERNATOR LINE CURRENT

↕ 50A/DIV.

⟷ 500 μSEC/DIV.



ALTERNATOR NEUTRAL CURRENT

↕ 10A/DIV.

⟷ 200 μSEC/DIV.

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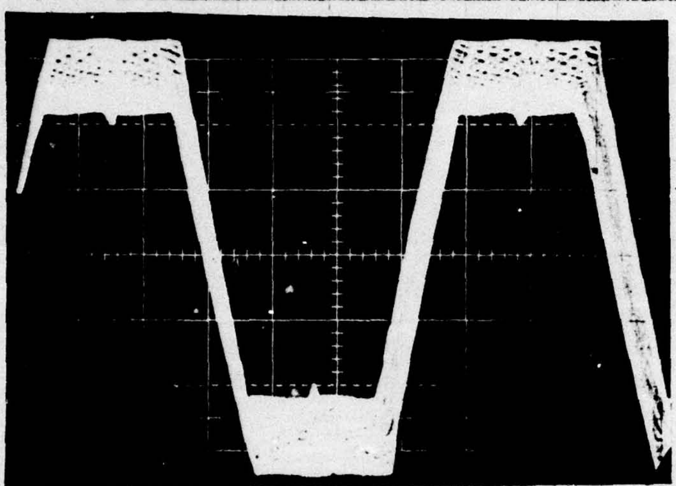
| | | APPROVED | | |

ALTERNATOR L-T-N VOLTAGES AT OUTPUT OF MATCHING TRANFORMERS

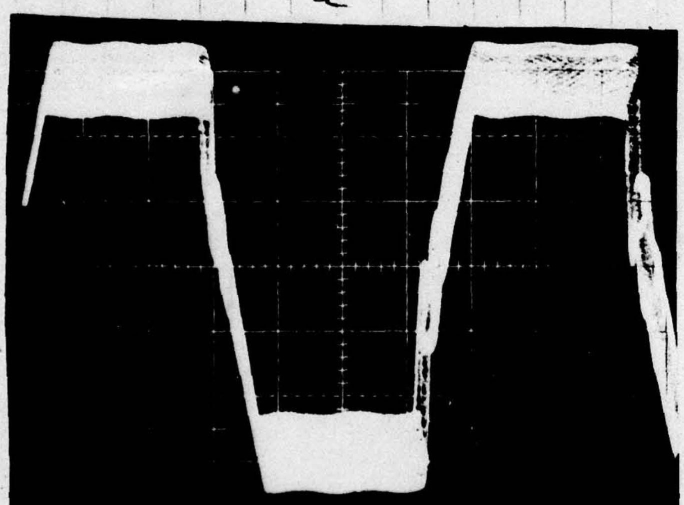


a

125.3 Vrms

NO LOAD ON INVERTER - INVERTER OUTPUT VOLTAGE = 120 Vrms L-T-N

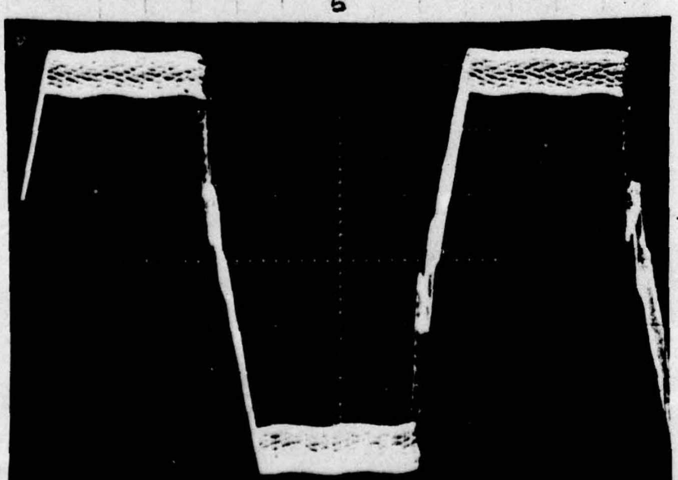
↕ 50V/DIV.
↔ 100 µSEC/DIV.



b

135 Vrms

INVERTER LOAD 11 KW, PF = 1.0 3φ, 400 HZ
INVERTER OUTPUT VOLTAGE = 120.8 Vrms



c

133.9 Vrms

INVERTER LOAD 11 KW, PF = 0.8 3φ 400 HZ

INVERTER OUTPUT VOLTAGE = 119.8 Vrms

(TWO WIRE INPUT TO INVERTER)

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DE 255 REV. 12-66

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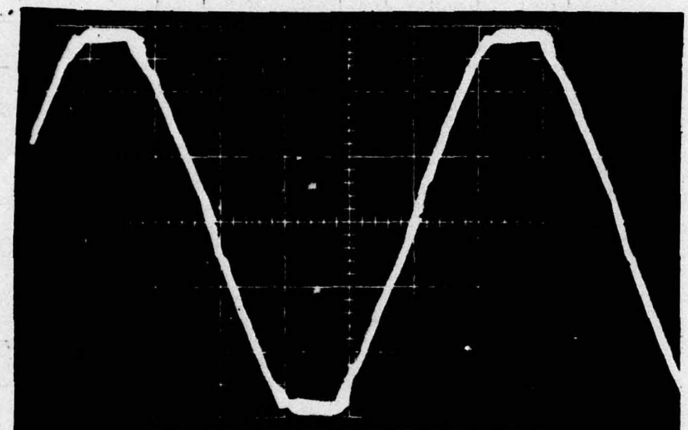
APPROVED

ALTERNATOR L-T-L VOLTAGES AT OUTPUT OF MATCHING TRANSFORMERS



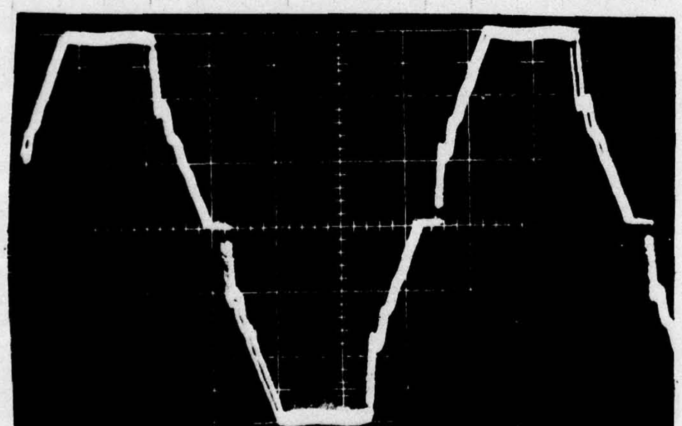
a

209.4 Vrms

NO LOAD ON INVERTER

INVERTER OUTPUT
VOLTAGE = 208 Vrms L-T-L

↕ 100V / DIV
⟷ 100 μsec / DIV.

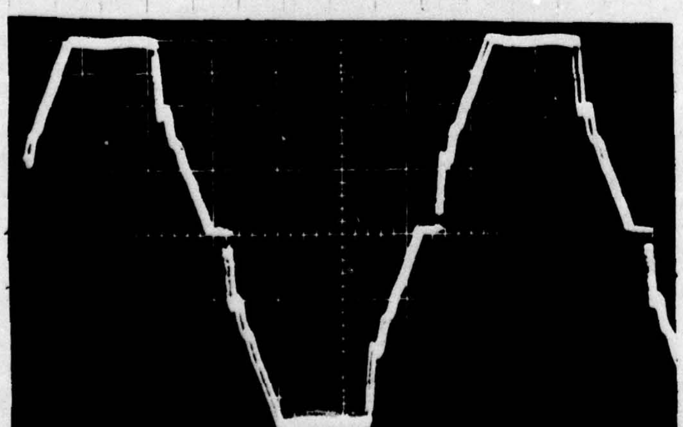


b

222.9 V rms

INVERTER LOAD 11 KW
PF = 1.0 3φ 400 HZ

INVERTER OUTPUT
VOLTAGE = 209.0 Vrms L-T-L



c

223 Vrms

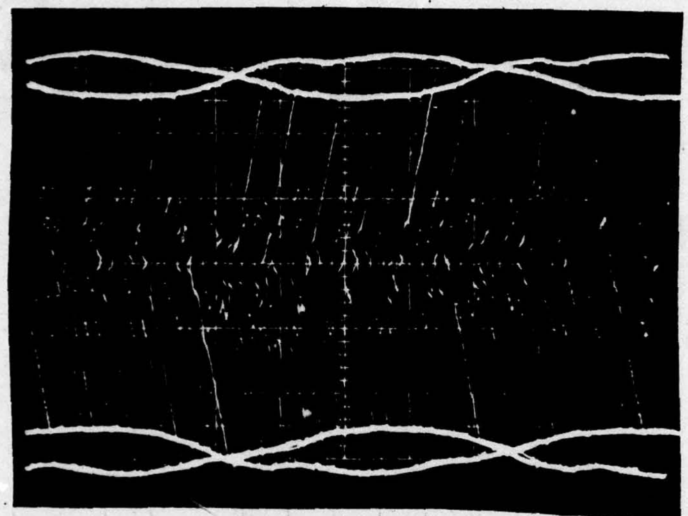
INVERTER LOAD 11 KW
PF = 0.8 3φ 400 HZ

INVERTER OUTPUT
VOLTAGE = 207.5 Vrms L-T-L

(TWO WIRE INPUT TO INVERTER)

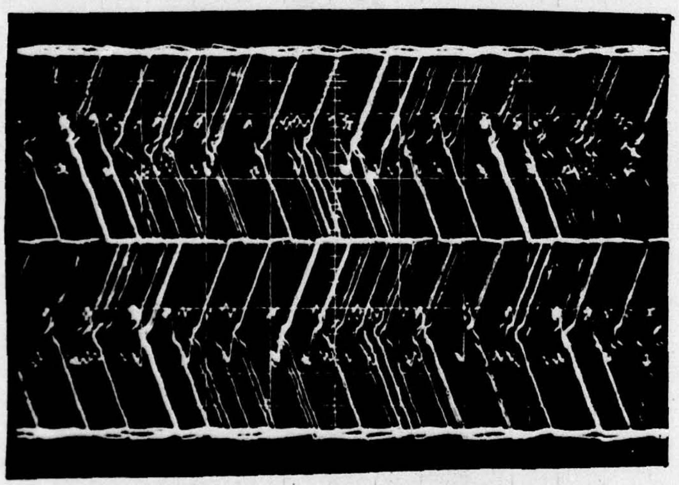
DISTRIBUTION:

## INVERTER INPUT AND OUTPUT AC VOLTAGES



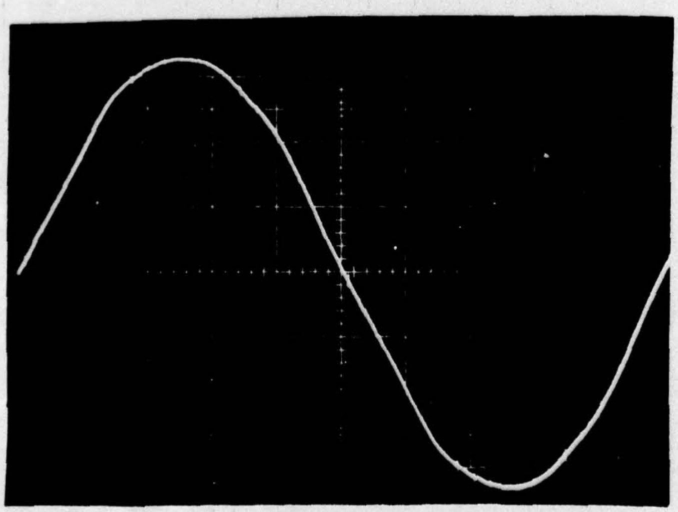
ALTERNATOR L-T-N OUTPUT VOLTAGE

SAME AS PHOTO C ON PAGE 85A BUT SYNC. CHANGED TO SHOW AMPLITUDE MODULATION.



ALTERNATOR L-T-L OUTPUT VOLTAGE

SAME AS PHOTO C ON PAGE 85 B BUT SYNC. CHANGED TO SHOW AMPLITUDE MODULATION.



INVERTER OUTPUT L-T-N VOLTAGE.

119.8 Vrms

LOAD 11KW, PF=0.8
3$\phi$, 400 HZ

(TWO WIRE INVERTER INPUT)

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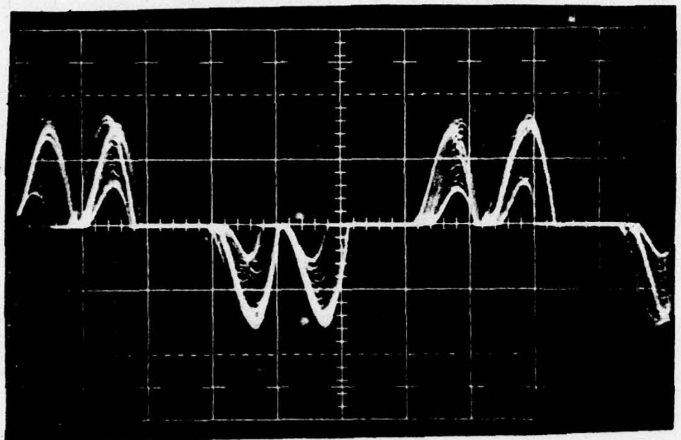
| | | APPROVED | | |

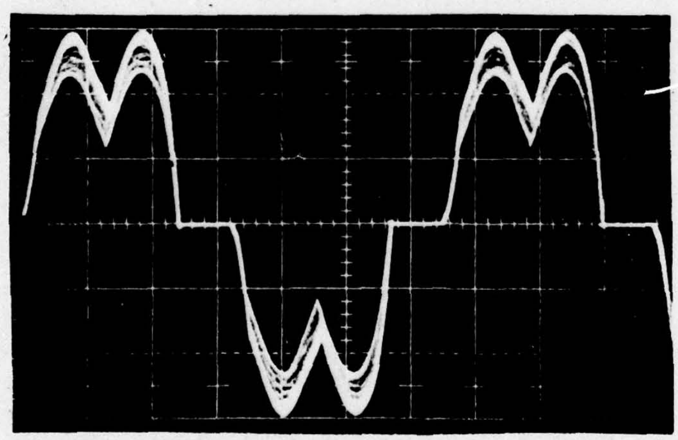
ALTERNATOR LINE CURRENTS AT OUTPUT OF MATCHING TRANSFORMERS



6.34 A rms

NO LOAD ON INVERTER

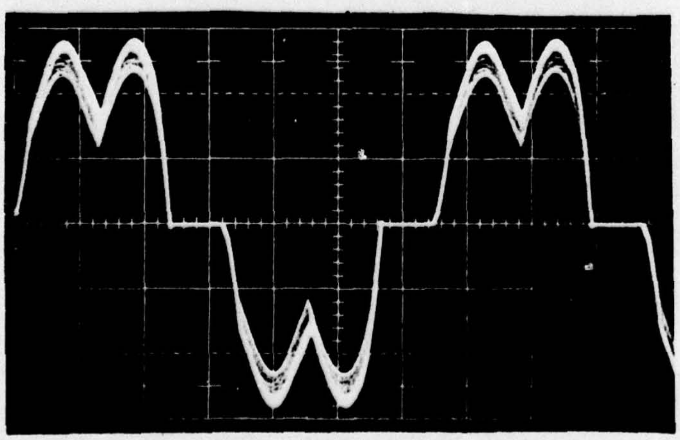
↕ 10 A/DIV.
↔ 100 μSEC/DIV.



37.14 A rms

INVERTER LOAD 11KW
PF = 1.0 3φ 400 HZ

↕ 20A/DIV. ↔ 100 μ SEC/DIV.



36.0 A rms

INVERTER LOAD 11KW
PF = 0.8 3φ 400 HZ

↕ 20A/DIV. ↔ 100 μ SEC/DIV.

DISTRIBUTION:

15 KVA FREQUENCY CONVERTER

Test Results (Design Data) Item 0005

CDRL Item A002

Modification No. P0006

Contract No. DAAK02-72-C-0210

**DELCO ELECTRONICS**

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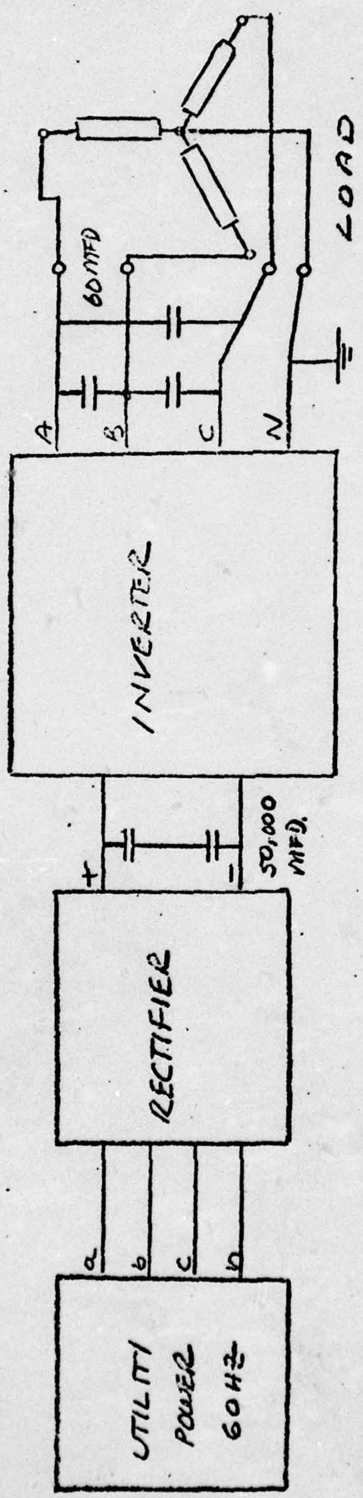


CONNECTIONS FOR 400HZ, THREE PHASE POWER

(STEP TRANSISTORS NOT CONNECTED)

FOR DATA ON PAGES 86-113

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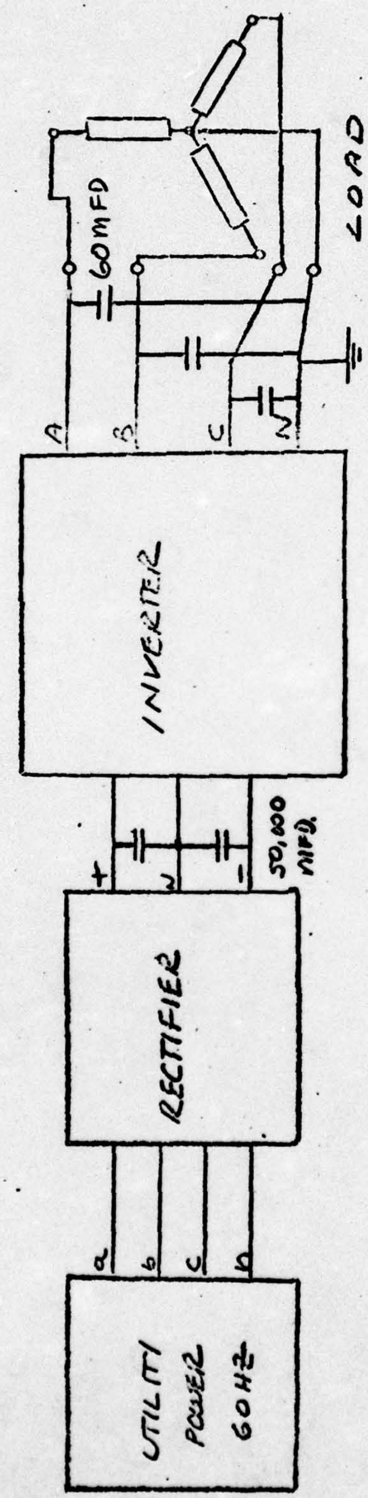


CONNECTIONS FOR 60 HZ, THREE PHASE POWER

FOR DATA ON PAGES 86-113

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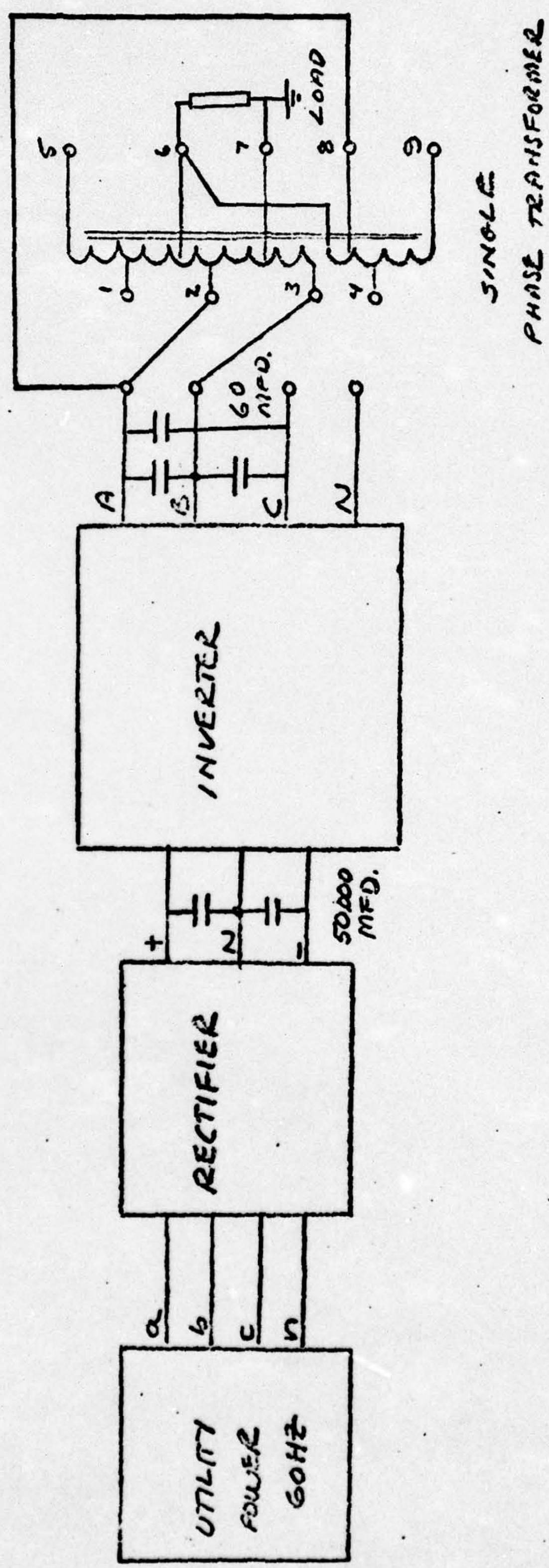


CONNECTIONS FOR 400 HZ, SINGLE 1PHASE, TWO WIRE POWER

(STEP TRANSISTORS NOT CONNECTED)

FOR DATA ON PAGES 86-113

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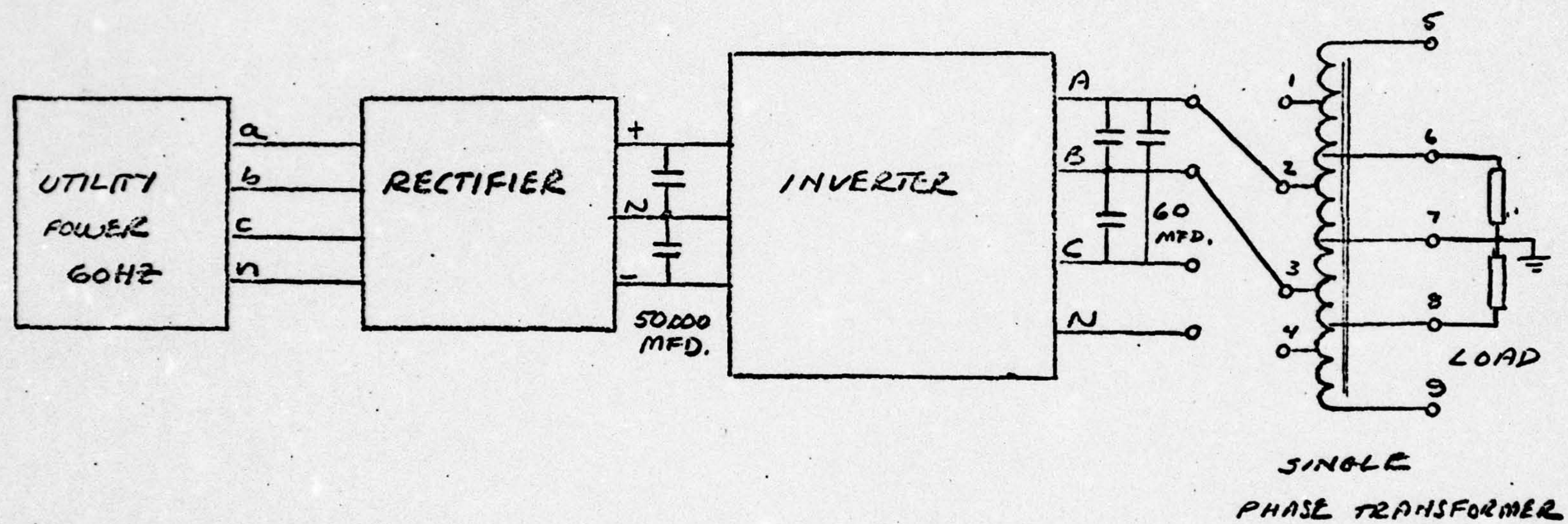


CONNECTIONS FOR 400HZ, SINGLE PHASE, THREE WIRE POWER

(STEP TRANSISTORS NOT CONNECTED)

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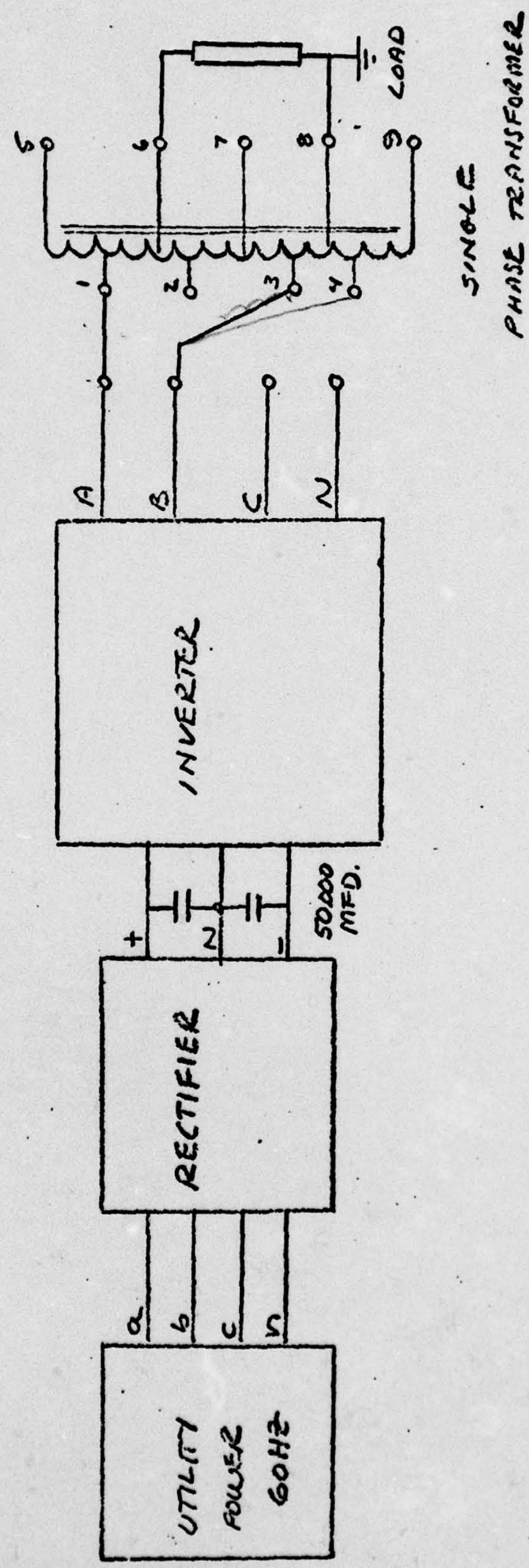
| | | APPROVED | | |




CONNECTIONS FOR 60HZ, SINGLE PHASE, TWO WIRE POWER

FOR DATA ON PAGES 86-113

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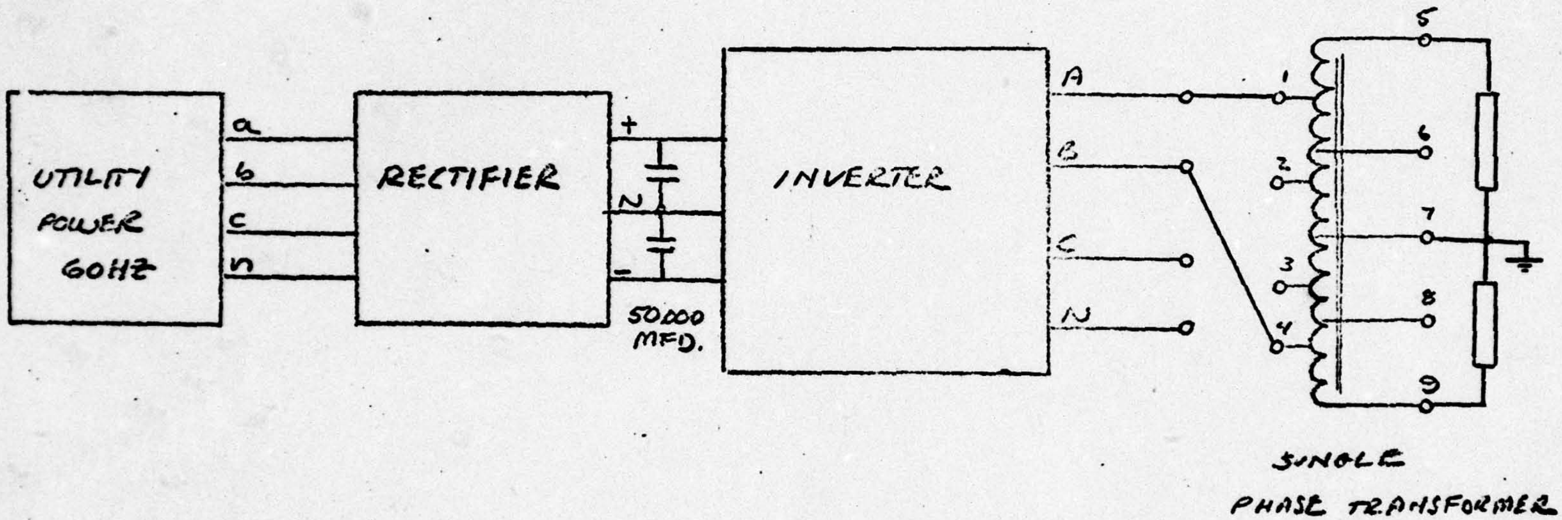


CONNECTIONS FOR 60HZ, SINGLE PHASE, THREE WIRE POWER

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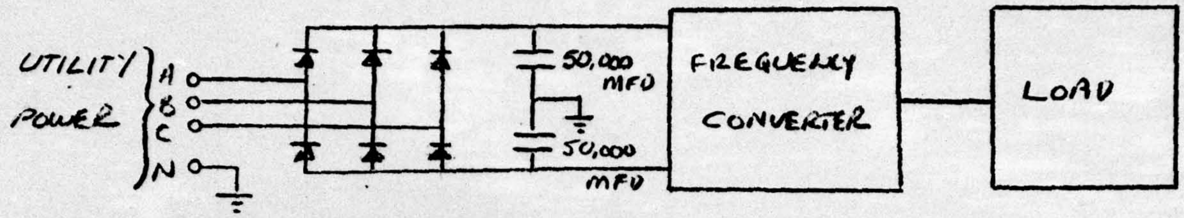
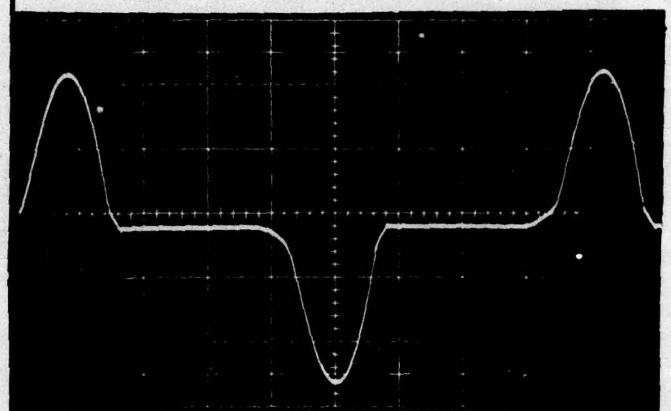
| TEST RESULTS 15KVA FREQUENCY CONVERTER ITEM 0005 CONTRACT NO. DAAK02-72-C-0210 | PREPARED CORRY  DATE 1/23/74<br>CHECKED<br>APPROVED |

## REFERENCE DESIGN TEST DATA

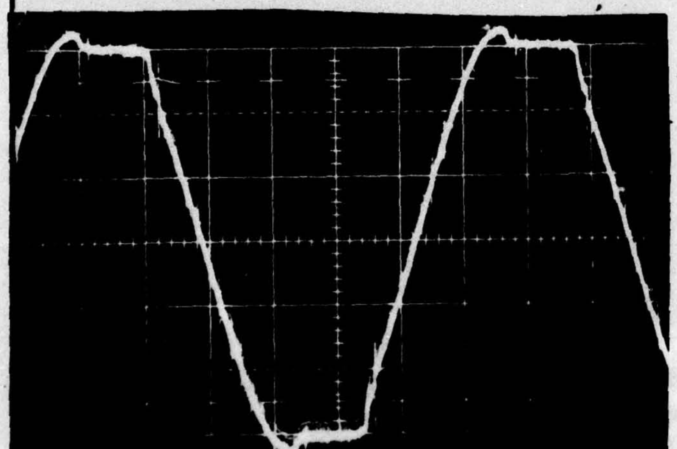


60 Hz UTILITY LINE CURRENT $I_A$

↕ 50A/DIV.

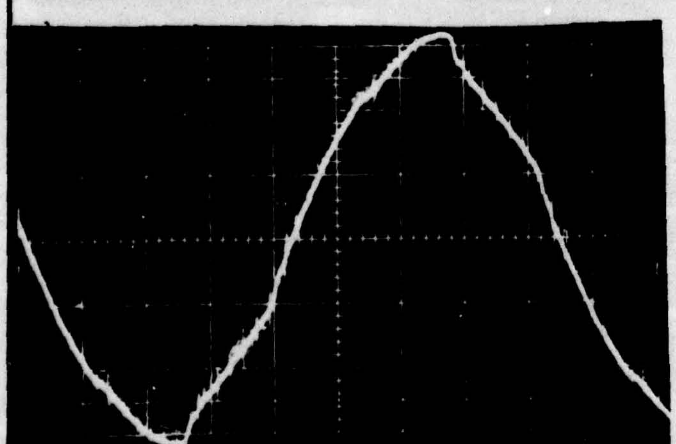
⟷ 2ms/DIV.



UTILITY LINE-TO-NEUTRAL VOLTAGE $V_{A-N}$

↕ 50V/DIV

⟷ 2ms/DIV.



UTILITY LINE-TO-LINE VOLTAGE $V_{A-B}$

↕ 100V/DIV.

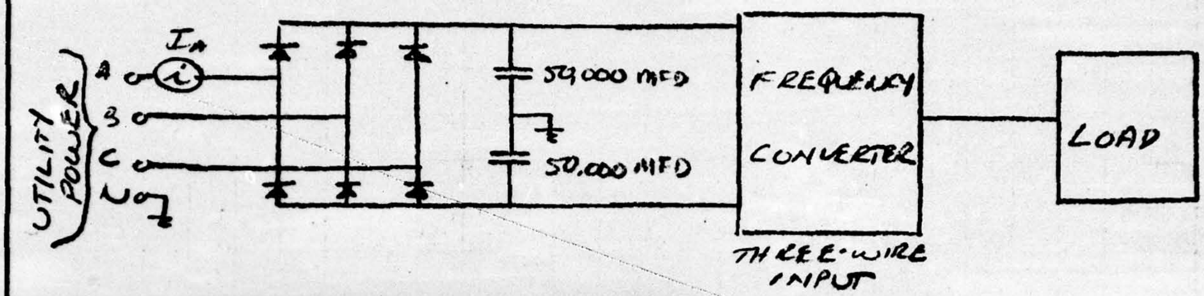
⟷ 2ms/DIV.

FREQUENCY CONVERTER LOAD = 11KW, PF = 0.8, 400 Hz

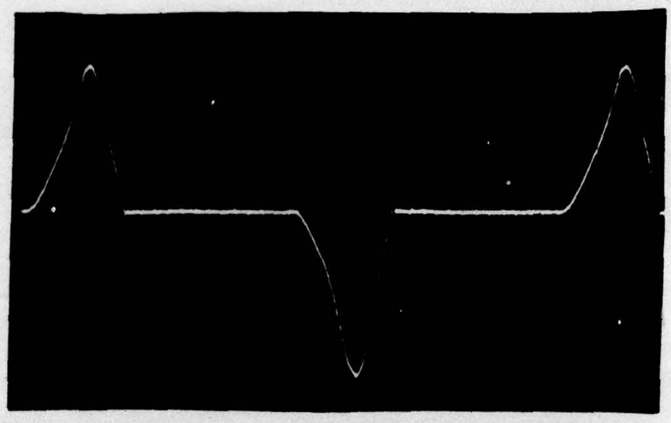


DISTRIBUTION:

CURRENT WAVEFORMS – POWER LINES
AT INPUT TO RECTIFIER



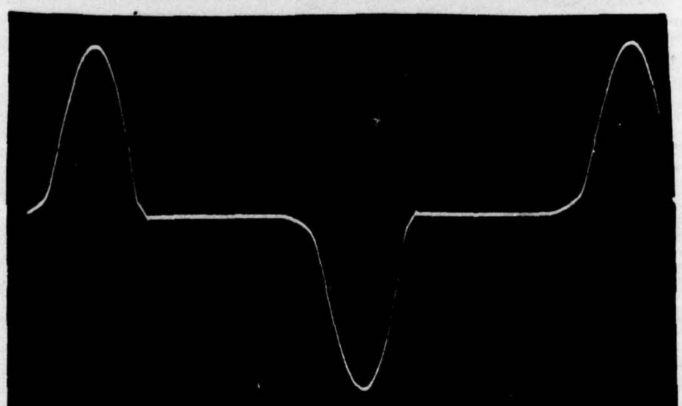

60 HZ UTILITY LINE CURRENTS $I_A$



NO LOAD ON FREQUENCY CONVERTER

10A/DIV. ↔ 2ms/DIV.

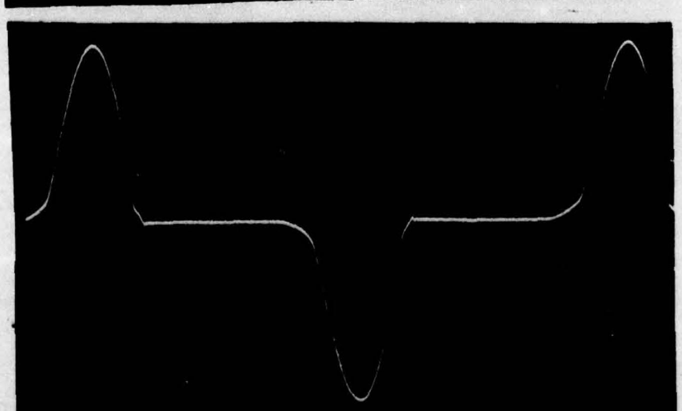
8.38 AMPS RMS



11KW, PF = 1.0, 400 HZ 3φ LOAD ON F.C.

50A/DIV. ↔ 2ms/DIV.

56.6 AMPS RMS



11KW, PF = 0.8

50A/DIV. ↔ 2ms/DIV.

56 AMPS RMS

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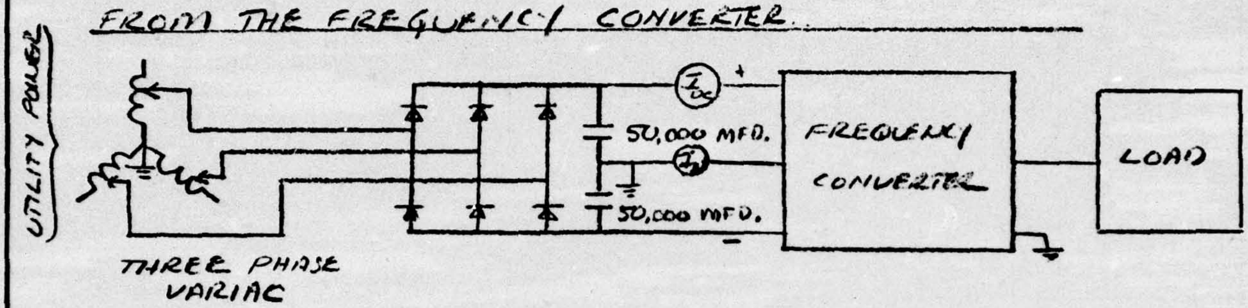
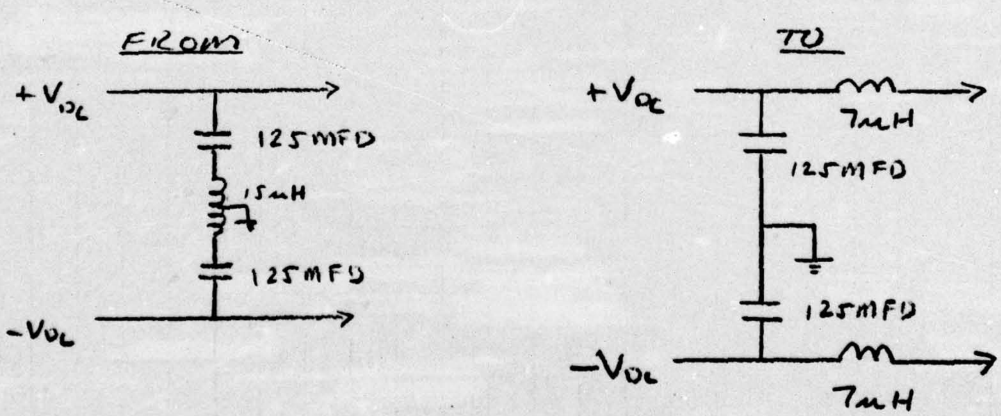
- INVESTIGATION OF THE PERFORMANCE OF THE TURBO-ALTERNATOR FREQUENCY CONVERTER WHEN OPERATED FROM A LABORATORY POWER SUPPLY.

- DEMONSTRATION OF 15KVA POWER CAPABILITY FROM THE FREQUENCY CONVERTER.




LABORATORY POWER SUPPLY

FREQUENCY CONVERTER INPUT CHANGED




FOR $\frac{di}{dt}$ PROTECTION WHEN OPERATING FROM THE LABORATORY POWER SUPPLY

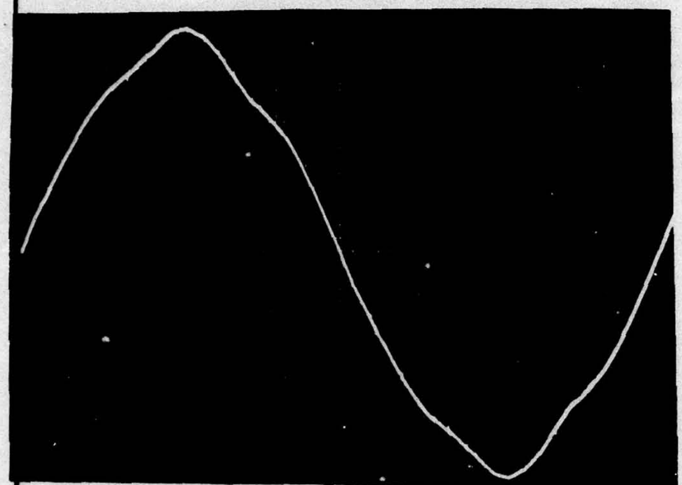
(REACTIVE RETURN DIODES CONNECTED TO POWER SOURCE SIDE OF 7 mH INDUCTORS SHOWN ABOVE)

DISTRIBUTION:

FREQUENCY CONVERTER OUTPUT VOLTAGES

400 HZ THREE PHASE
(NO TRANSISTORS)

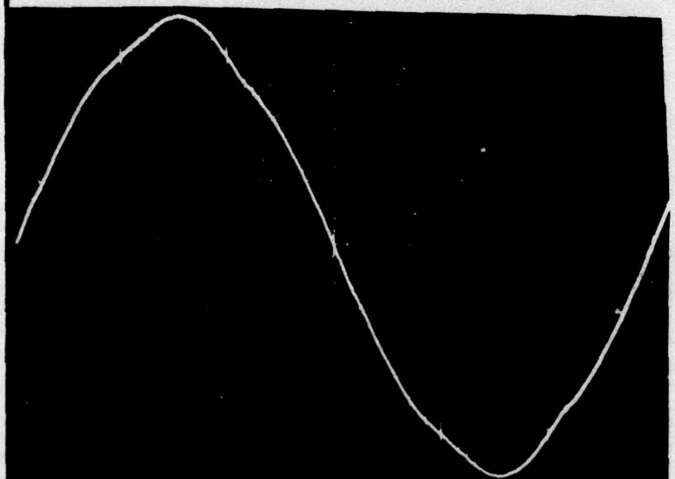
L-T-N VOLTAGES



NO LOAD

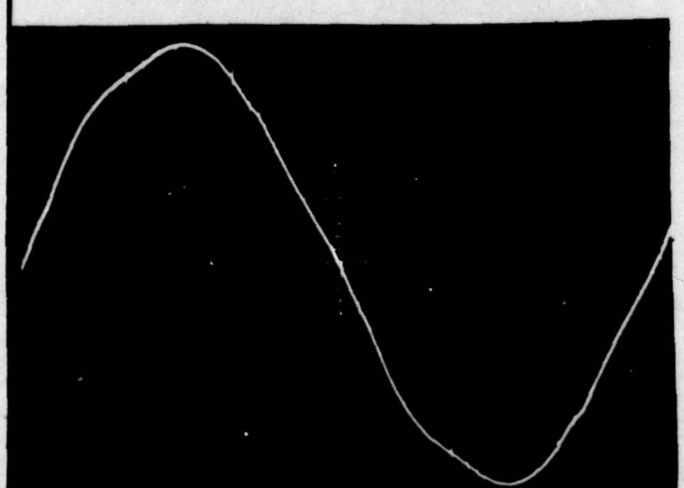
THD= 3.68%

50V/DIV.



16 KW, PF=1.0

THD=2.44%

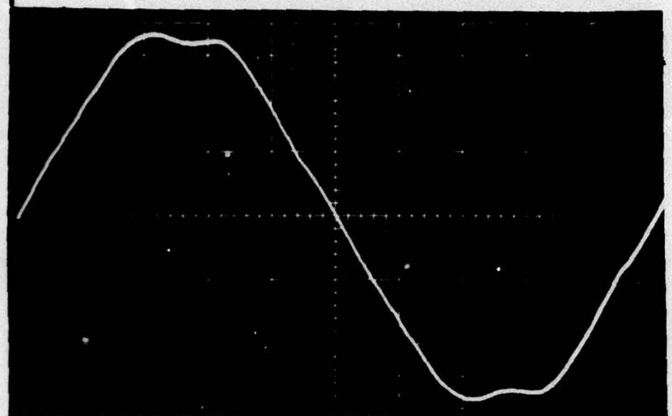


16 KW, PF=0.8

THD= 2.8%

DISTRIBUTION:

FREQUENCY CONVERTER OUTPUT VOLTAGES



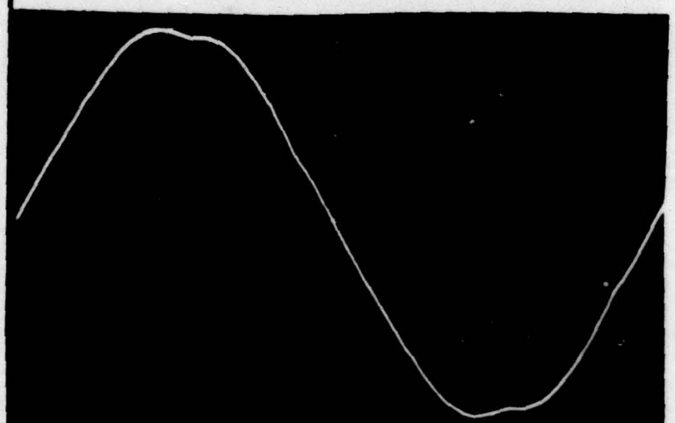
400HZ THREE PHASE
(NO TRANSISTORS)

L-T-L VOLTAGES

NO LOAD

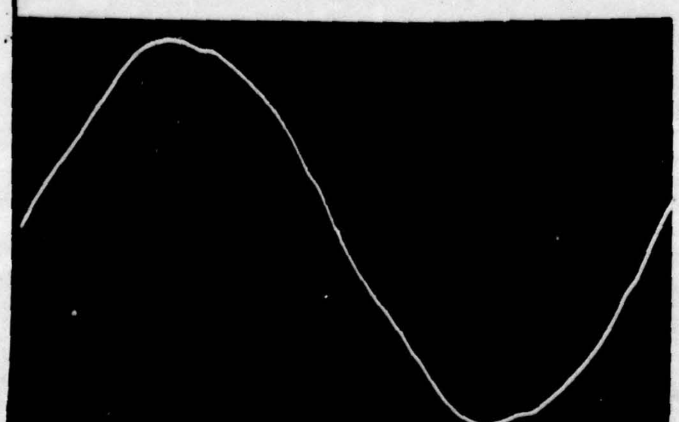
THD= 3.68%

100V/DIV.



16KW, PF= 1.0

THD= 2.44%



16KW, PF = 0.8

THD= 2.8%

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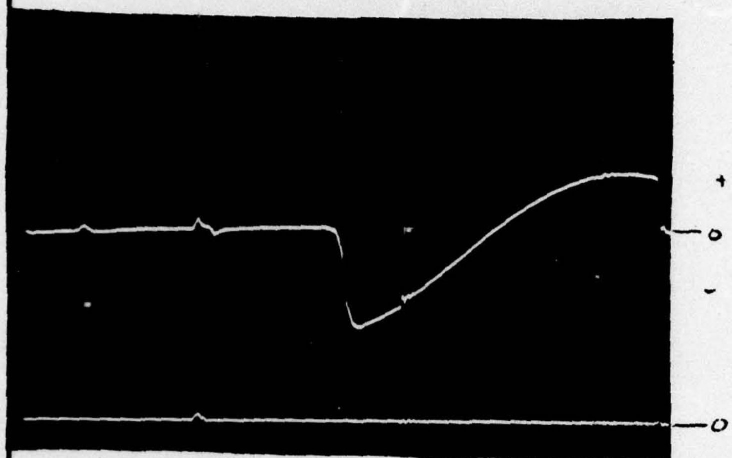
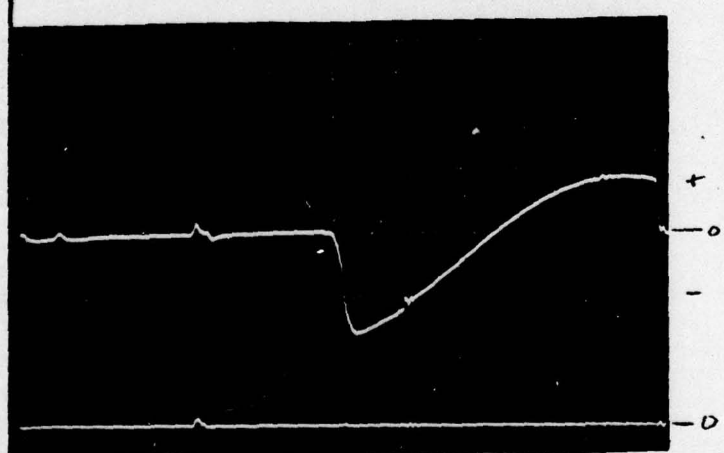
POWER CENTER THYRISTOR REVERSE COMMUTATION VOLTAGE AND ANODE CURRENT



400 HZ THREE PHASE
NO LOAD
THYRISTOR ANODE VOLTAGE
↕ 50V/DIV.
↔ 10 μ SEC/DIV.

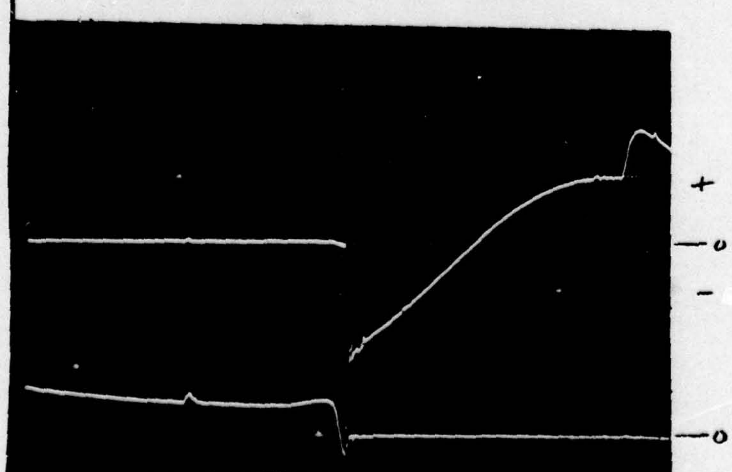
ANODE CURRENT
↕ 50 A/DIV.



16KW, PF = 1.0

THYRISTOR ANODE VOLTAGE

ANODE CURRENT



16KW, PF = 0.8

THYRISTOR ANODE VOLTAGE

ANODE CURRENT

(COMMUTATION BOOST VOLTAGE = ± 28VDC)

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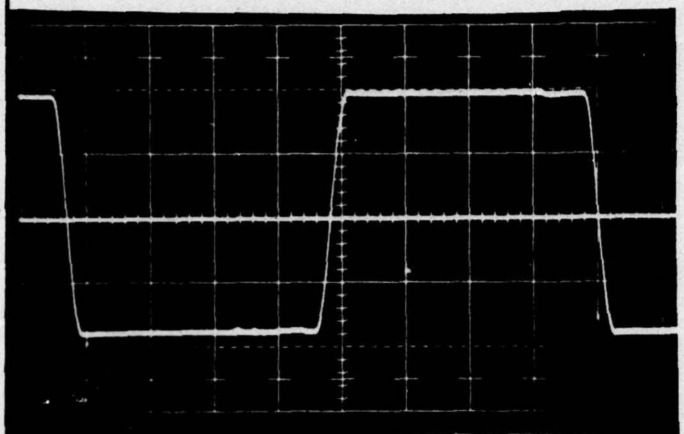
| | | APPROVED | | |

POWER CENTER COMMUTATION CAPACITOR VOLTAGE



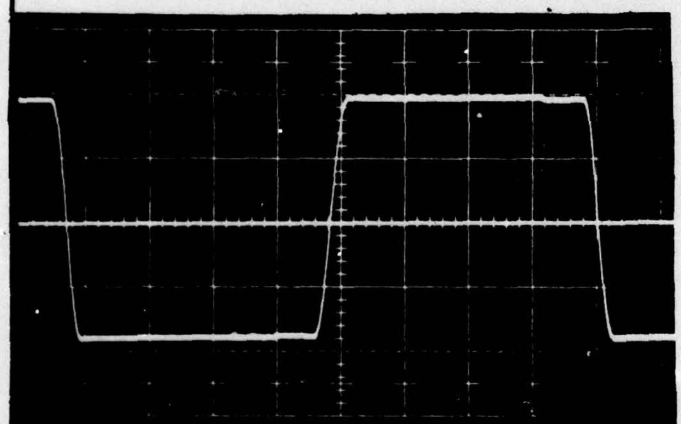
400 HZ THREE PHASE

COMMUTATION CAPACITOR VOLTAGE

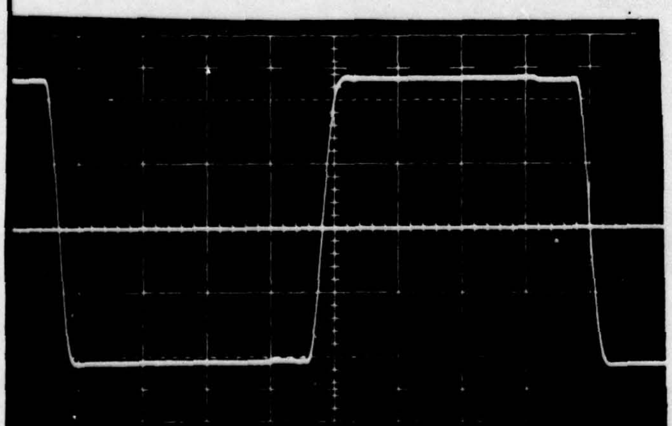
NO LOAD

↕ 50V / DIV.

↔ 100 μsec/DIV.



16KW, PF=1.0



16KW, PF=0.8

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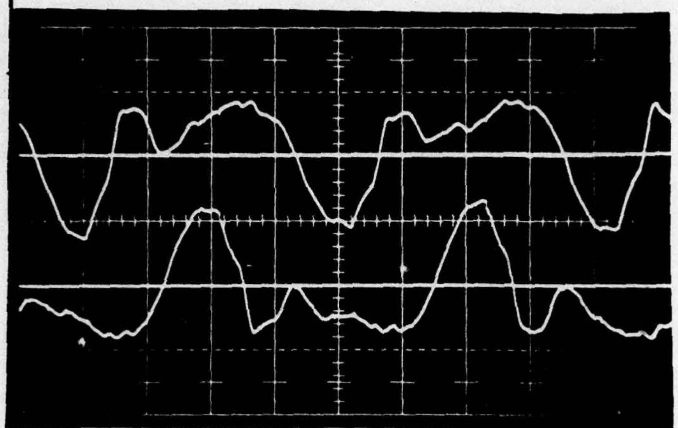
| | | APPROVED | | |

FREQUENCY CONVERTER INPUT CURRENTS

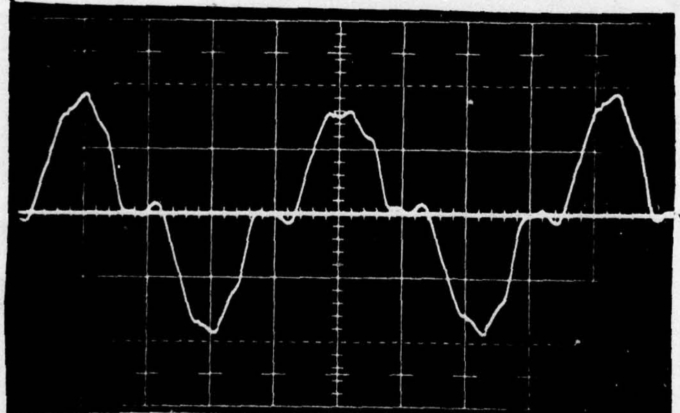


+
-0
-0
-

400HZ THREE PHASE
NO LOAD

↕ 50A/DIV.

⟷ 200 μSEC/DIV.

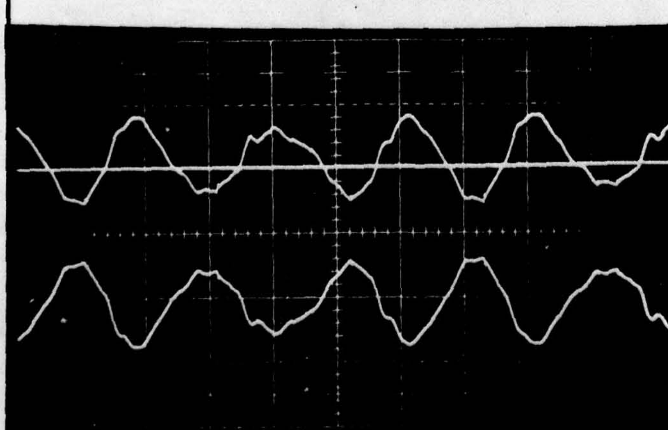


+
-0
-

NEUTRAL CURRENT

↕ 50A / DIV.

⟷ 200 μSEC/DIV.



+
-0
-0
-

± INPUT CURRENTS
WITH NEUTRAL
NOT CONNECTED.

↕ 50A/DIV.

⟷ 200 μSEC/DIV.

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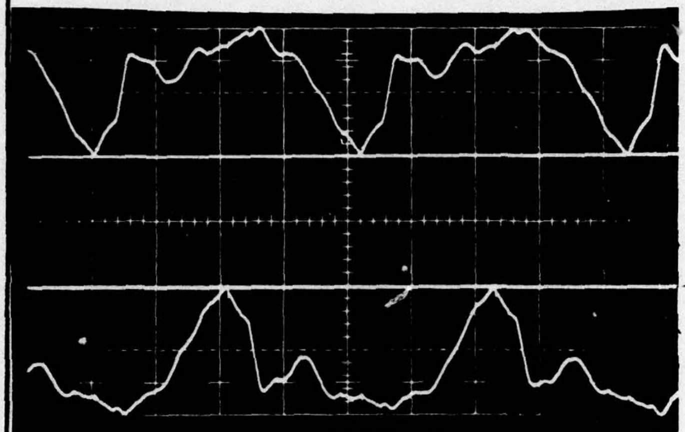
FREQUENCY CONVERTER INPUT CURRENTS

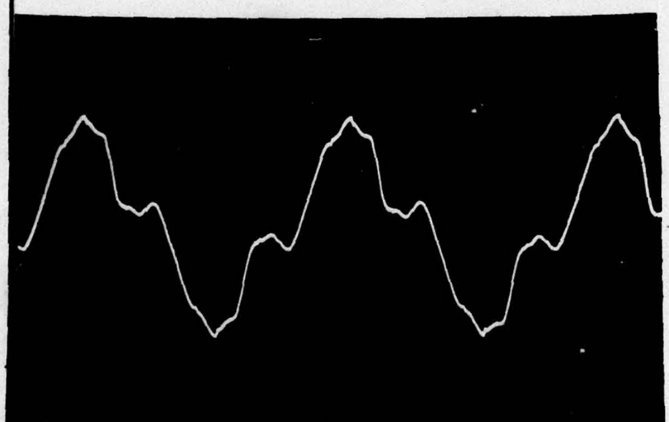



400HZ THREE PHASE

16KW, PF=1.0

↕ 50A/DIV.

⟷ 200μSEC/DIV.

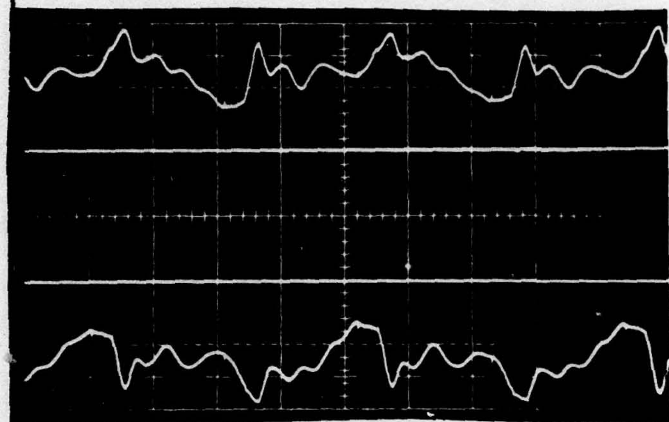



NEUTRAL CURRENT


± INPUT CURRENTS WITH NEUTRAL NOT CONNECTED.

DISTRIBUTION:

FREQUENCY CONVERTER INPUT CURRENTS

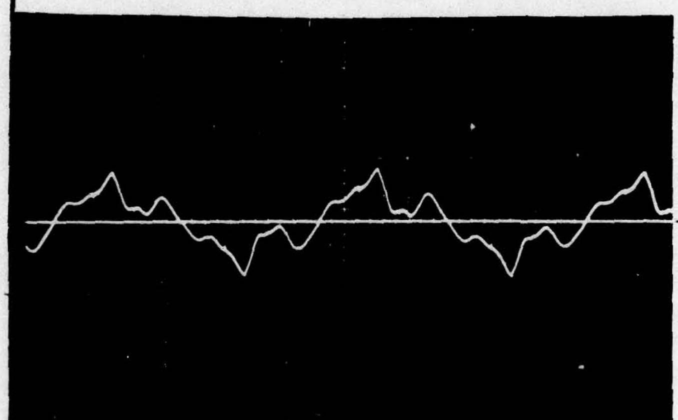


400 HZ THREE PHASE

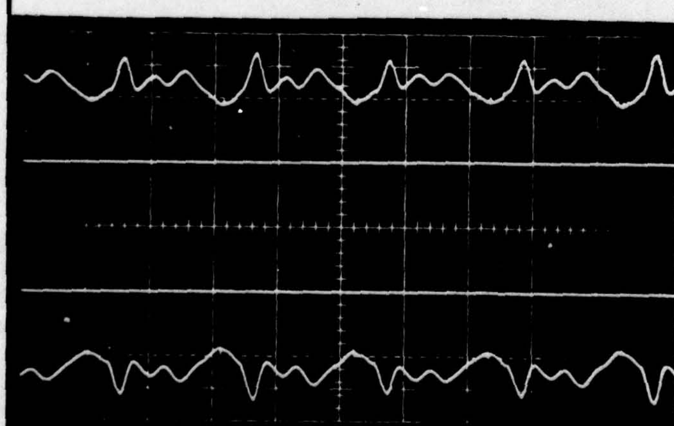
16KW, PF=0.8

↕ 50 A/DIV.

⟷ 200 μ SEC/DIV.



NEUTRAL CURRENT



± INPUT CURRENTS WITH NEUTRAL NOT CONNECTED

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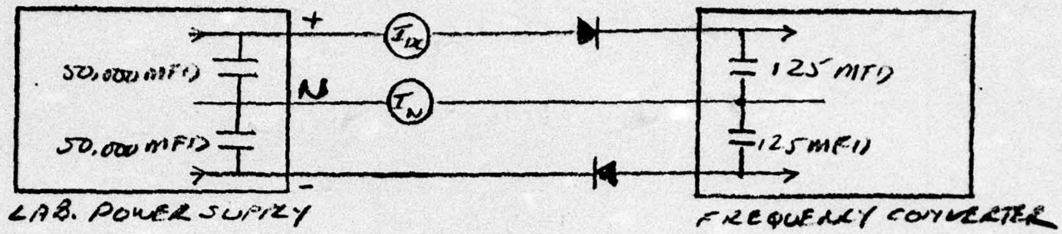
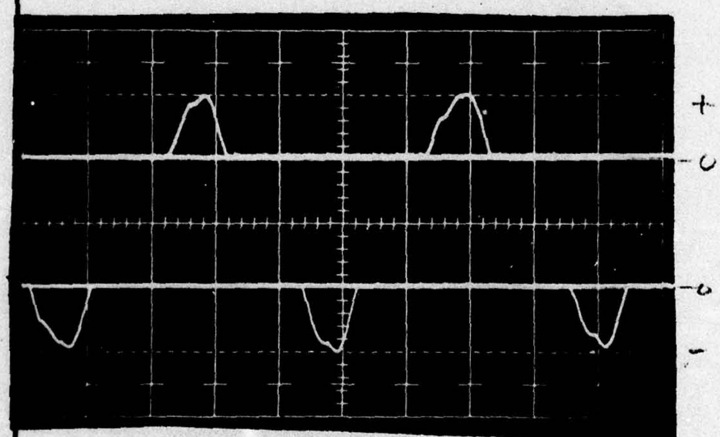
FREQUENCY CONVERTER INPUT CURRENTS




INVESTIGATION OF THE EFFECT DIODES IN SERIES WITH THE ± VOLTAGE LINES HAVE ON INPUT CURRENT WAVESHAPES.

(SYSTEM WORKS WITH NEUTRAL DISCONNECTED BUT THD INCREASES ABOUT 0.5%)

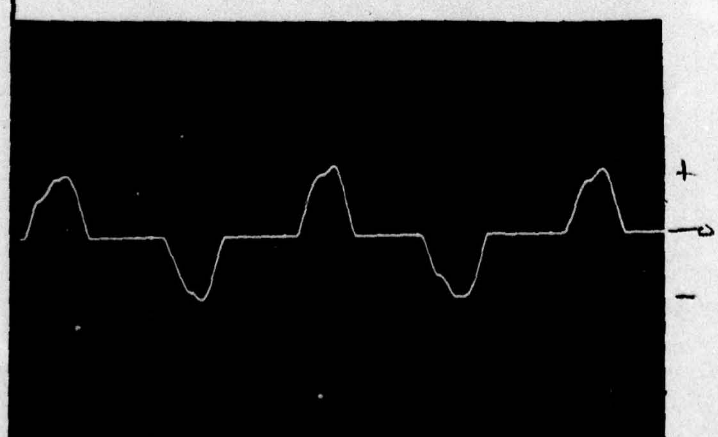



400HZ THREE PHASE

NO LOAD

↕ 50A/DIV.

⟷ 200μSEC/DIV.




NEUTRAL CURRENT

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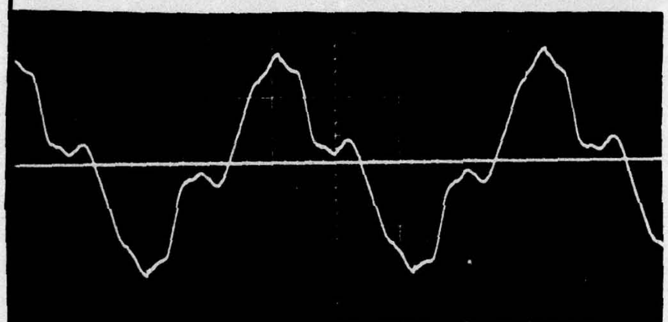
FREQUENCY CONVERTER INPUT CURRENTS

400 HZ THREE PHASE
(DIODES IN SERIES WITH
± VOLTAGE LINES)

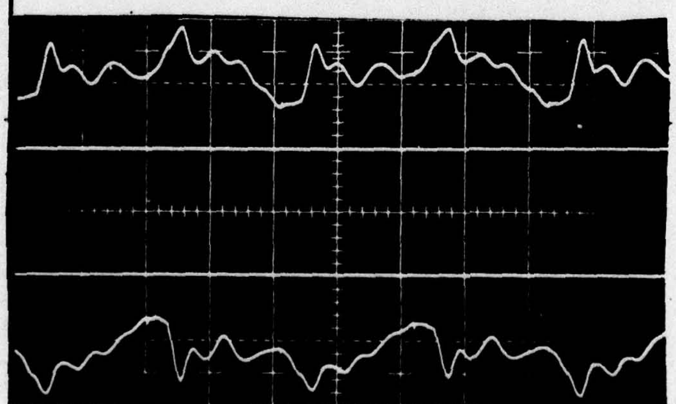
16KW, PF = 1.0

↕ 50A/DIV.

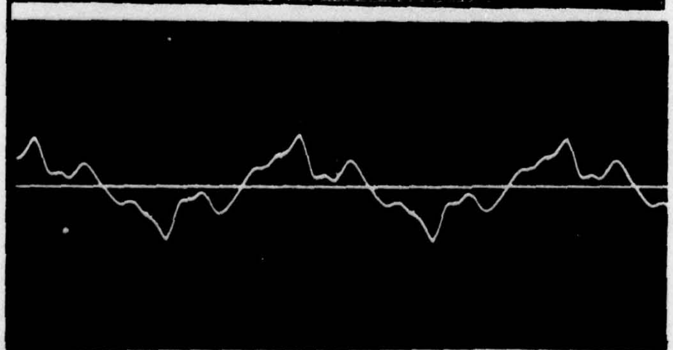
⟷ 200 μSEC/DIV.



NEUTRAL CURRENT



16KW, PF = 0.8



NEUTRAL CURRENT

DISTRIBUTION:

DE-255 REV. 12-66

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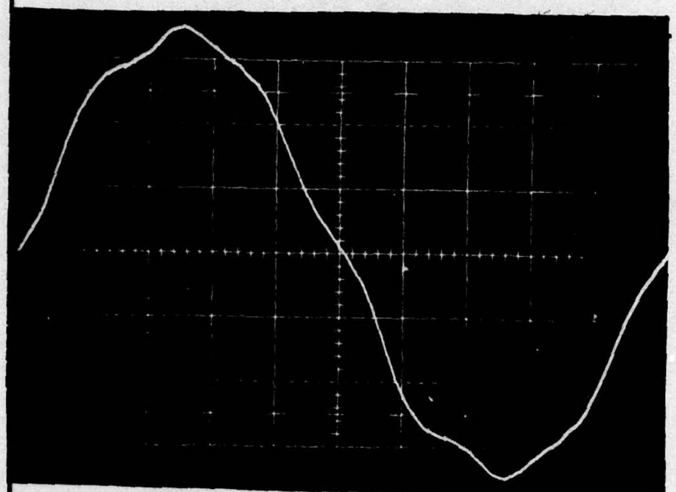
OUTPUT VOLTAGES FOR CIRCUIT ON PAGE 94

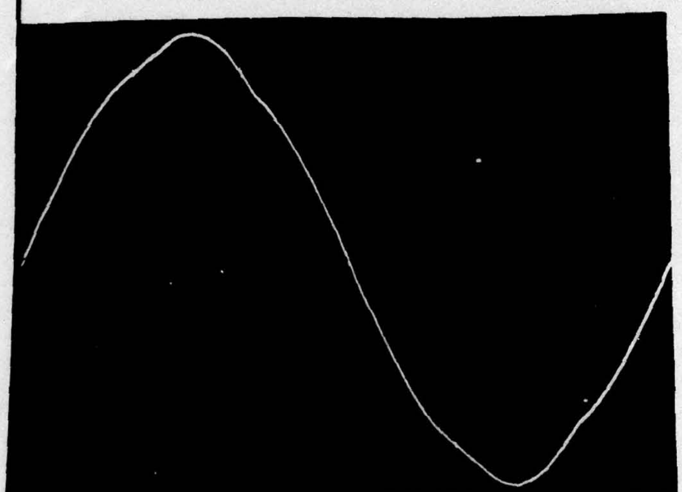


400HZ THREE PHASE
L-T-N VOLTAGES

NO LOAD

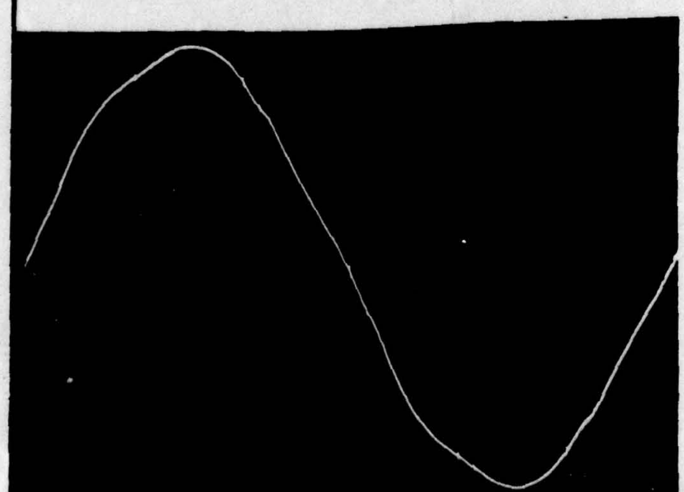
THD= 4.97%

↕ 50V/DIV.



16KW, PF=1.0

THD= 2.44%



16KW, PF= 0.8

THD= 2.83%

DISTRIBUTION:

DE-255 REV. 12-66

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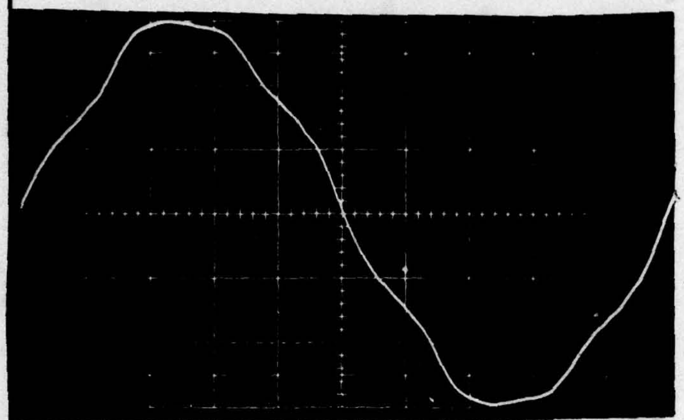
OUTPUT VOLTAGES FOR CIRCUIT ON PAGE 95

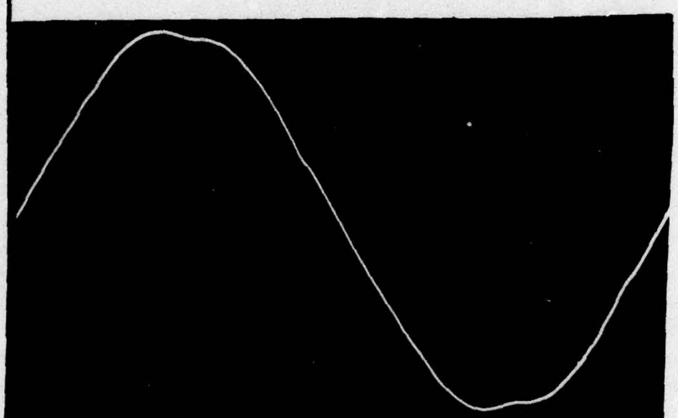


400 HZ THREE PHASE
L-T-L VOLTAGES

NO LOAD

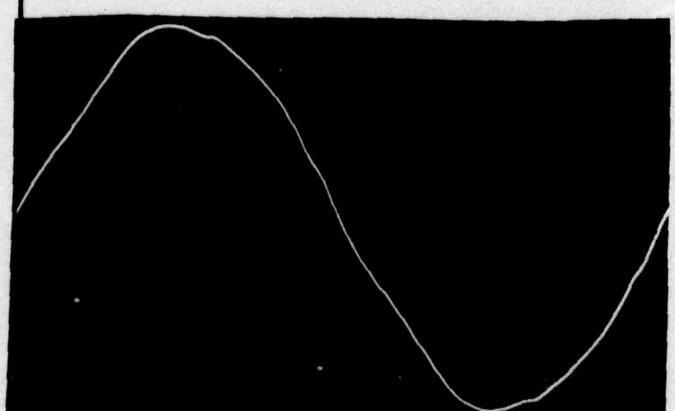
THD = 4.95%

↕ 100V/DIV.



16KW, PF = 1.0

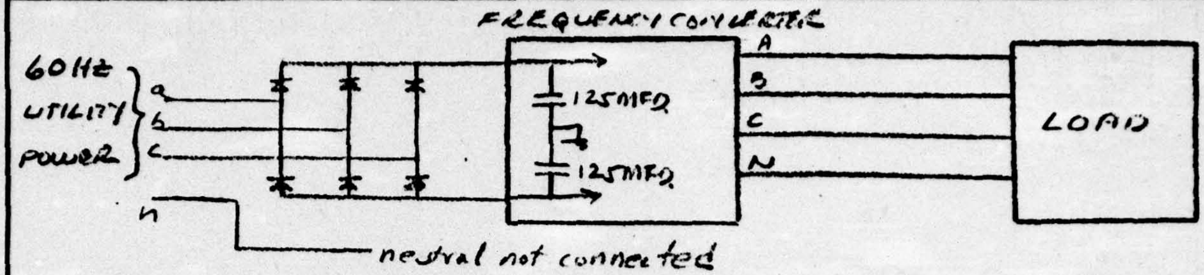
THD = 2.42%



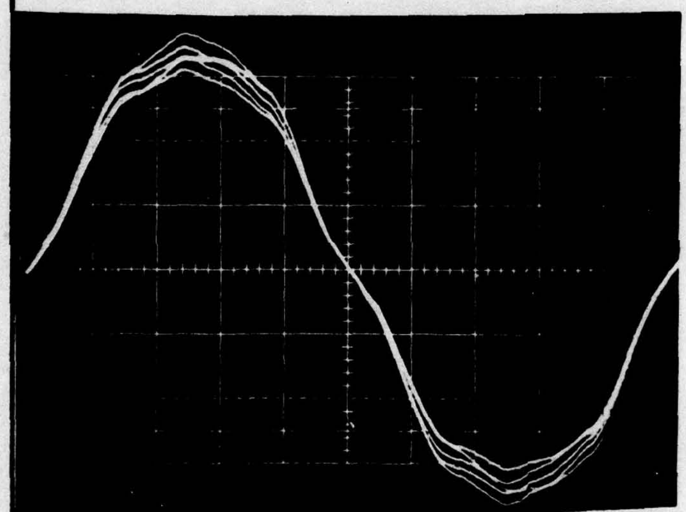
16KW, PF = 0.8

THD = 2.81%

DISTRIBUTION:




APPLYING 60HZ 3Φ POWER DIRECTLY TO FREQUENCY CHANGER INPUT. INVESTIGATION OF THE EFFECTS OF DC POWER SUPPLY RIPPLE NO FREQUENCY CONVERTER OUTPUT VOLTAGES.

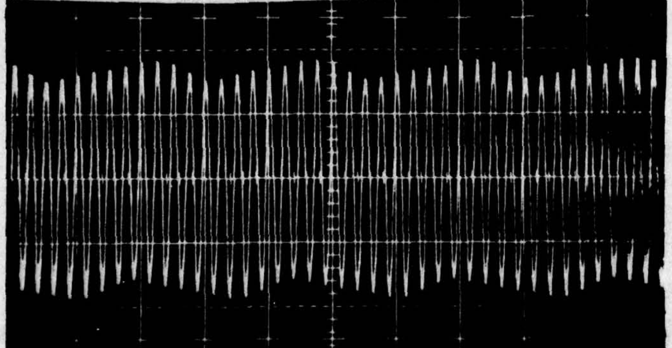


400HZ THREE PHASE
L-T-N VOLTAGES

NO LOAD
THD = 7%

↕ 50V/DIV

(FREQUENCY CONVERTER - NO TRANSISTORS - 60MFD L-T-L IN OUTPUT)



SAME AS ABOVE
BUT ↕ 100V/DIV
AND ↔ 10MS/DIV.

(NOTE: RIPPLE FREQUENCY ≈ 40HZ AND MAGNITUDE ≈ 35VOLTS.)

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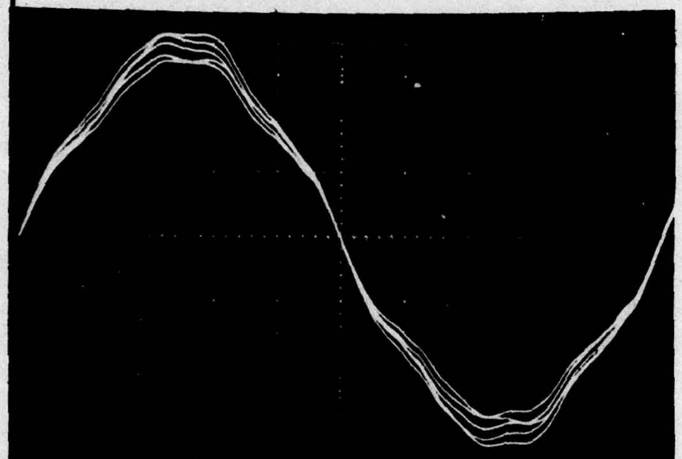
OUTPUT VOLTAGES FOR CIRCUIT ON PAGE 98

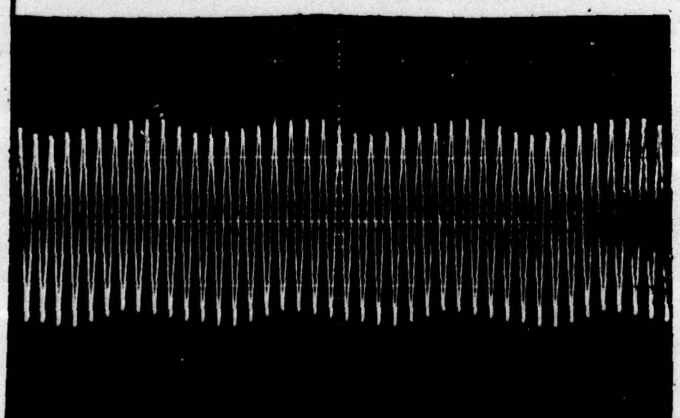


400 Hz THREE PHASE
L-T-L VOLTAGES

NO LOAD

THD = 7%

↕ 100V/DIV.



SAME AS ABOVE
BUT ↕ 200 V/DIV.
↔ 10 mS/DIV.

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DE 255 REV. 12-66

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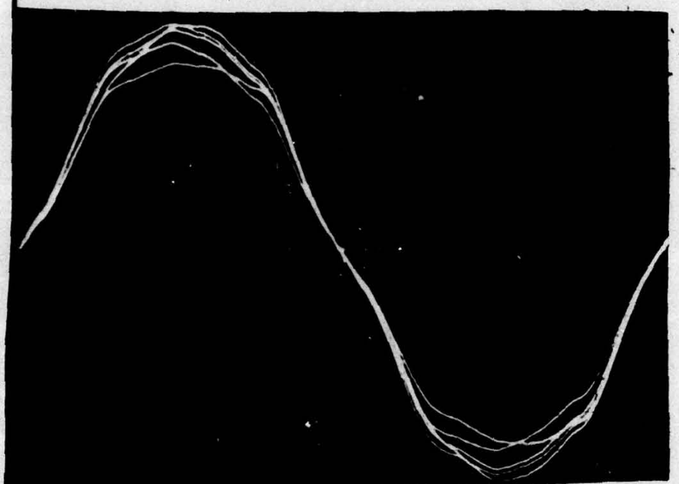
OUTPUT VOLTAGES FOR CIRCUIT ON PAGE 99

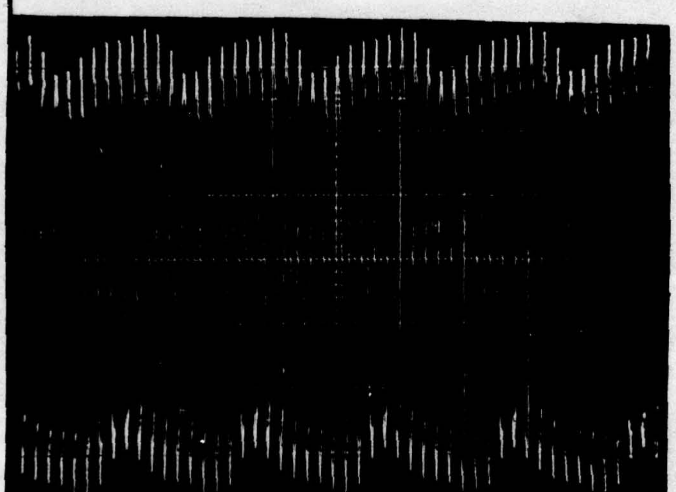


400HZ THREE PHASE
L-T-N VOLTAGES

11KW, PF = 1.0

THD = 7.3%

↕ 50V / DIV.



SAME AS ABOVE
↔ UNCALIBRATED

(NOTE: CONNECTING INPUT REC. NEUTRAL INCREASE STEP TRANSFORMER NOISE LEVEL, BUT REDUCES LOW FREQ. AMPLITUDE MODULATION LEVEL. NEUTRAL CURRENT HIGH.)

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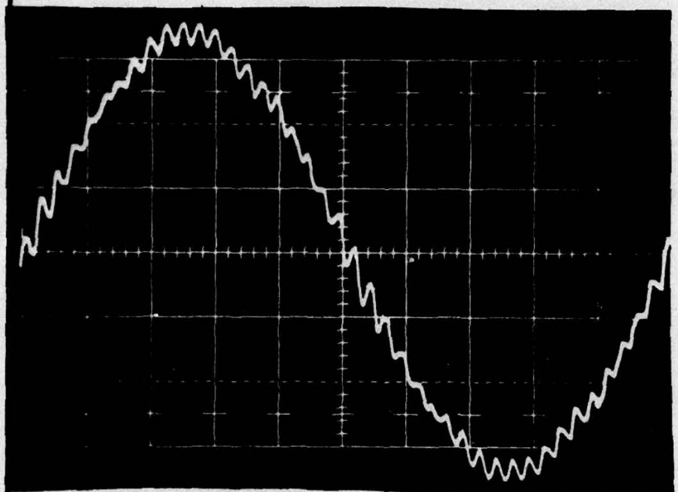
FREQUENCY CONVERTER OUTPUT VOLTAGES

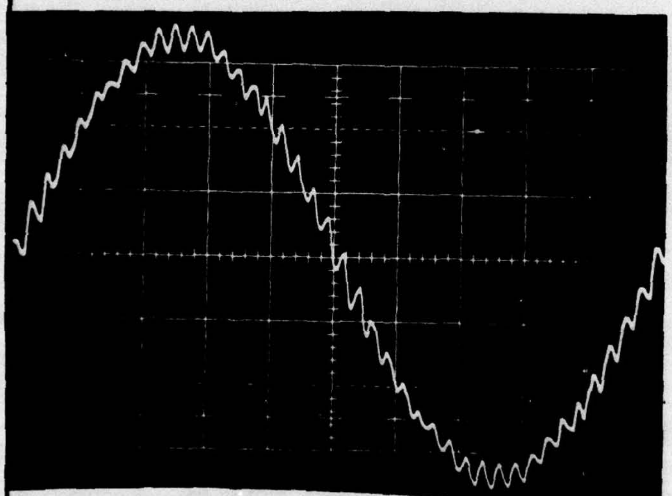


60HZ THREE PHASE
(60 MFD L-T-L)
L-T-N VOLTAGES

NO LOAD

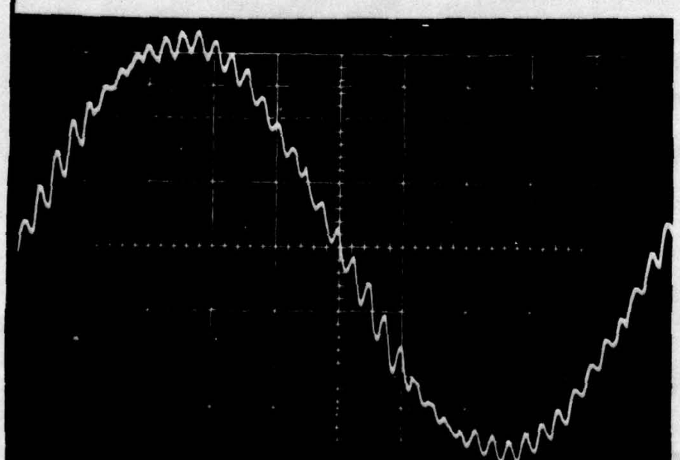
THD= 5%

50V/DIV.



16KW, PF=1.0

THD= 5.2%



16KW, PF=0.8

THD= 5.38%

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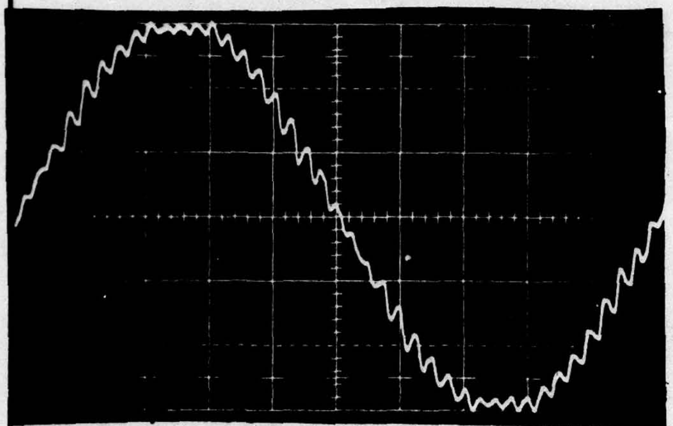
FREQUENCY CONVERTER OUTPUT VOLTAGES

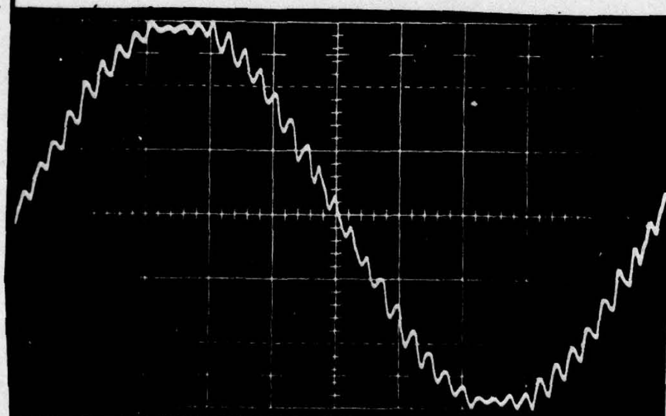


60 HZ THREE PHASE
(60 MFD L-T-L)
L-T-L VOLTAGES

NO LOAD

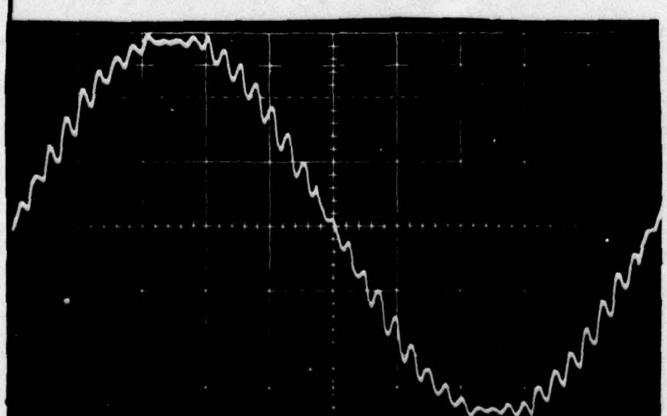
THD= 4.8%

100V/DIV.



16KW, PF= 1.0

THD= 5.0%



16KW, PF= 0.8

THD= 5.18%

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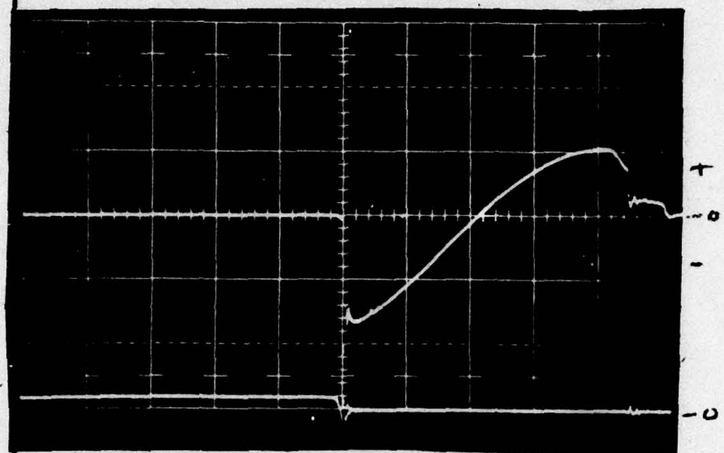
POWER CENTER THYRISTOR REVERSE COMMUTATION VOLTAGE AND ANODE CURRENT




60 HZ THREE PHASE

NO LOAD

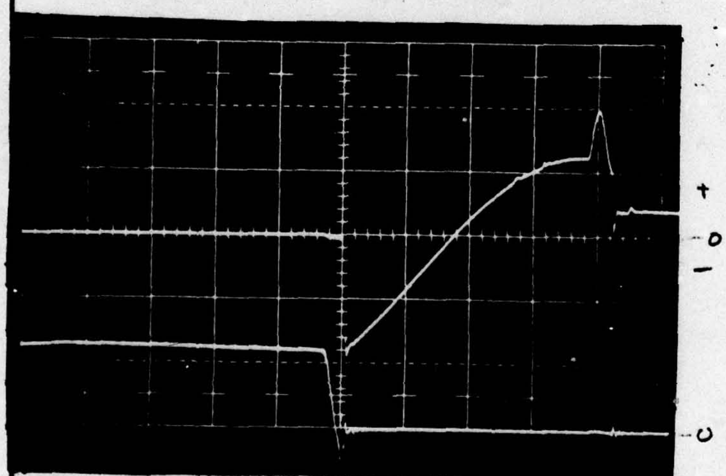
THYRISTOR ANODE VOLTAGE

↕ 50V/DIV.

⟷ 10 μSEC/DIV.

ANODE CURRENT

↕ 50 A/DIV.




16 KW, PF = 1.0

THYRISTOR ANODE VOLTAGE

ANODE CURRENT


16KW, PF = 0.8

THYRISTOR ANODE VOLTAGE

ANODE CURRENT

(COMMUTATION BOOST VOLTAGE = ± 24VDC, 60 MFD L-T-L)

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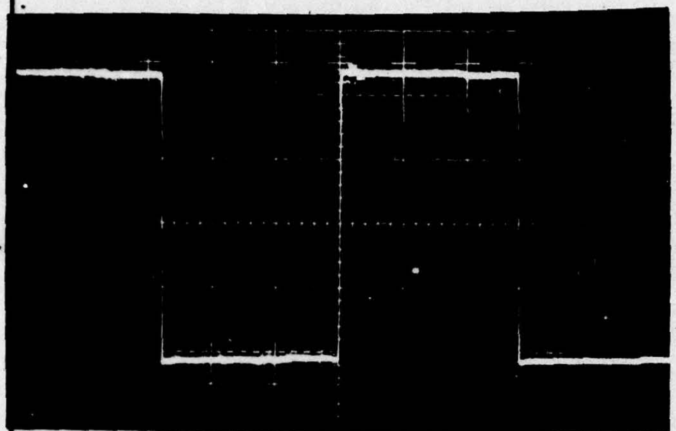
POWER CENTER COMMUTATION CAPACITOR VOLTAGE



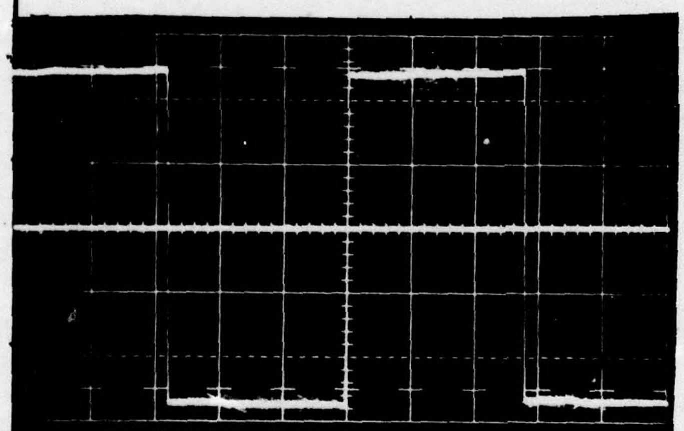
60 HZ THREE PHASE

COMMUTATION CAPACITOR VOLTAGE

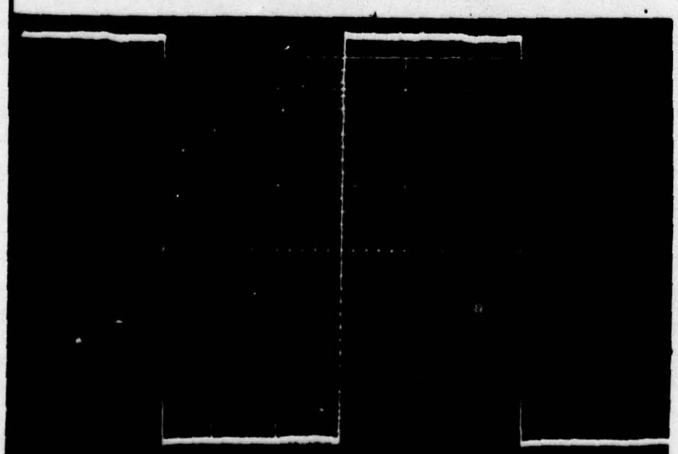
NO LOAD

↕ 50V/DIV.

⟷ 1 ms/DIV.



16KW, PF=1.0



16KW, PF= 0.8

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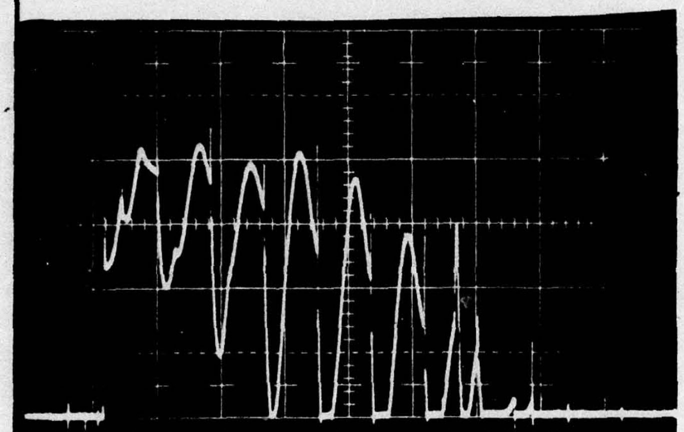
STEP COMMUTATION TRANSISTOR CURRENTS

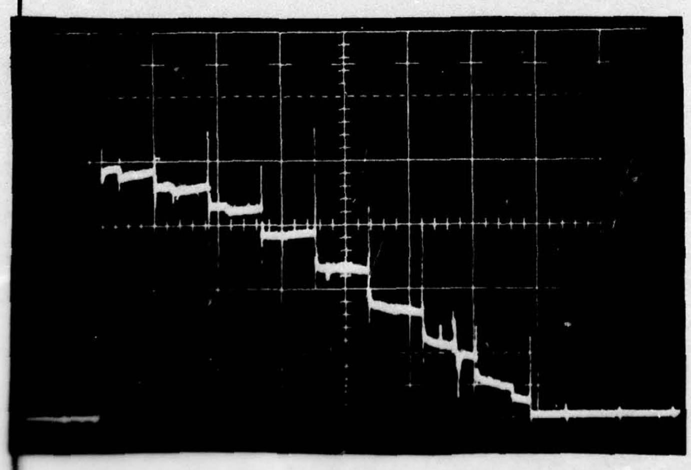
60 HZ THREE PHASE



COMMUTATION TRANSISTOR CURRENTS
LOAD = 16KW, PF = 0.8

WITH 60 MFD L-T-L IN OUTPUT OF FREQUENCY CONVERTER

↕ 20A/DIV. ↔ 500μSEC/DIV.



60 MFD L-T-L CAPACITORS REMOVED.

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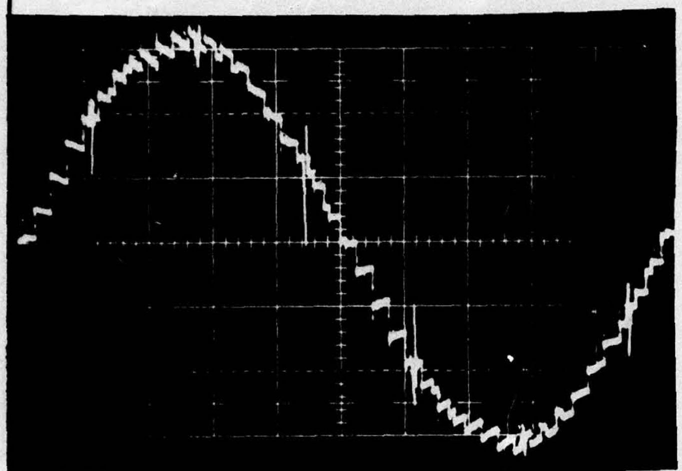
OUTPUT VOLTAGES WITH 60 MFD. L-T-L CAPACITORS REMOVED

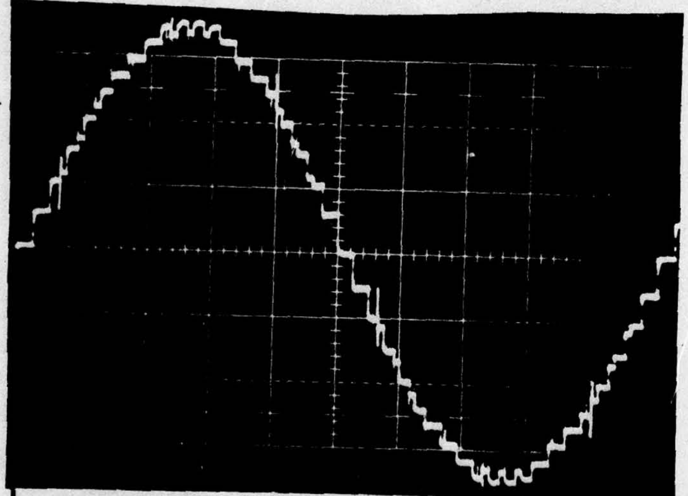


60 HZ THREE PHASE
L-T-N VOLTAGES

NO LOAD

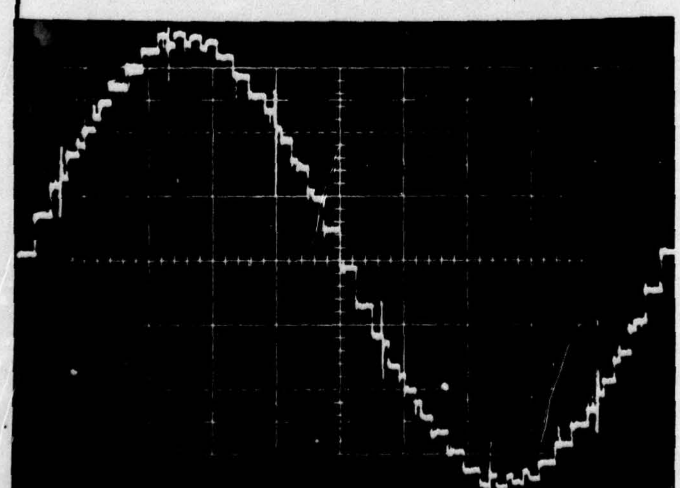
THD = 4.9%

50V/DIV.



16KW, PF=1.0

THD= 3.8%



16KW, PF=0.8

THD= 4.2%

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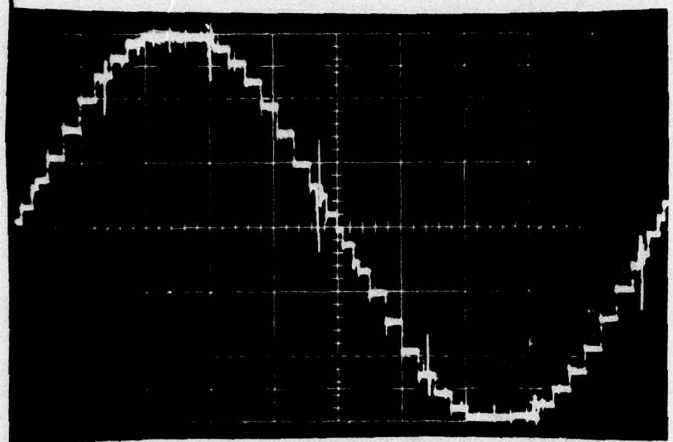
OUTPUT VOLTAGES WITH 60 MFD L-T-L CAPACITORS REMOVED

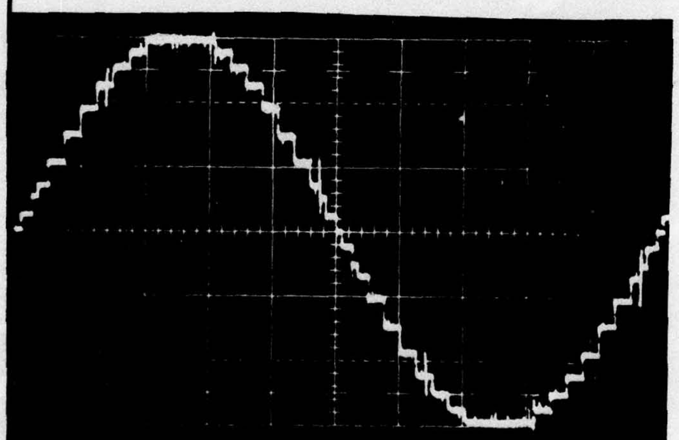


60 HZ THREE PHASE
L-T-L VOLTAGES

NO LOAD

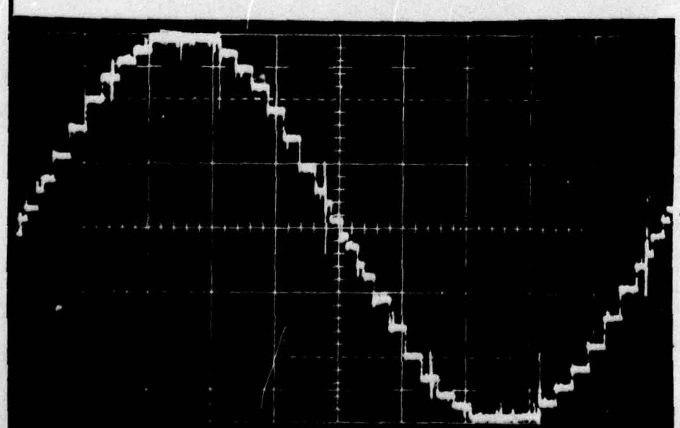
THD= 4.9%

100V/DIV.



16KW, PF=1.0

THD= 3.8%



16KW, PF=0.8

THD= 4.2%

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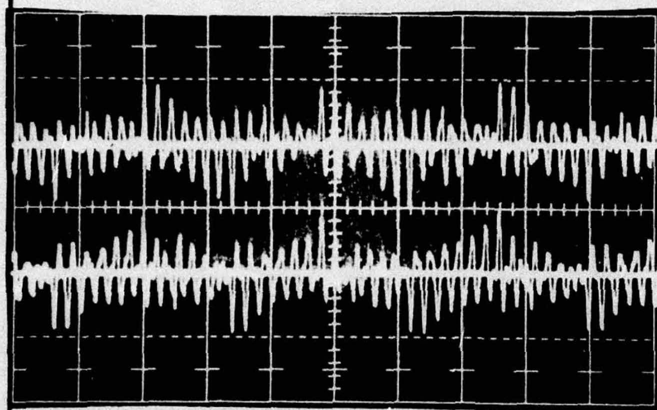
FREQUENCY CONVERTER INPUT CURRENTS
(60 MFD. L-T-L IN OUTPUT)

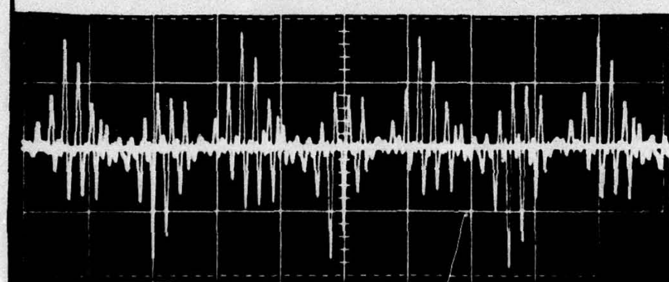


60HZ THREE PHASE

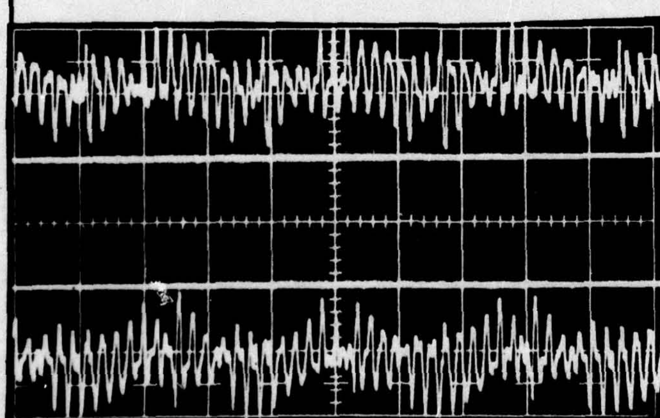
NO LOAD

↕ 50A / DIV.

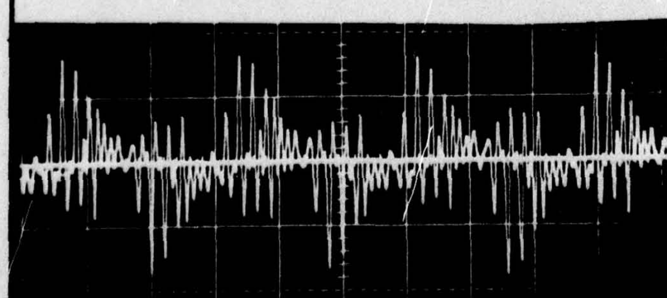
↔ 2MS/DIV.



NEUTRAL CURRENT



16KW, PF= 1.0



NEUTRAL CURRENT

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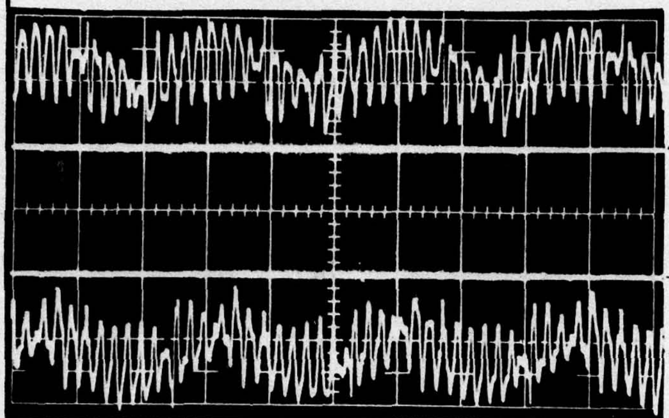
FREQUENCY CONVERTER INPUT CURRENTS

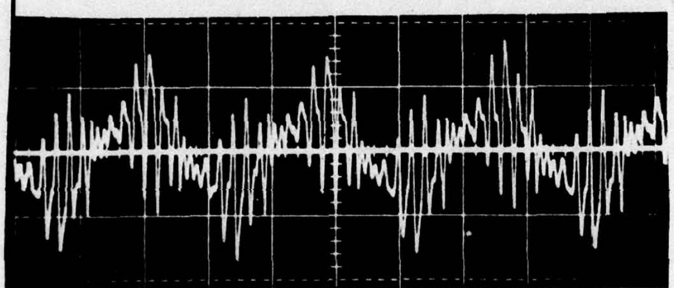


+
0
0
−

16KW, PF= 0.8

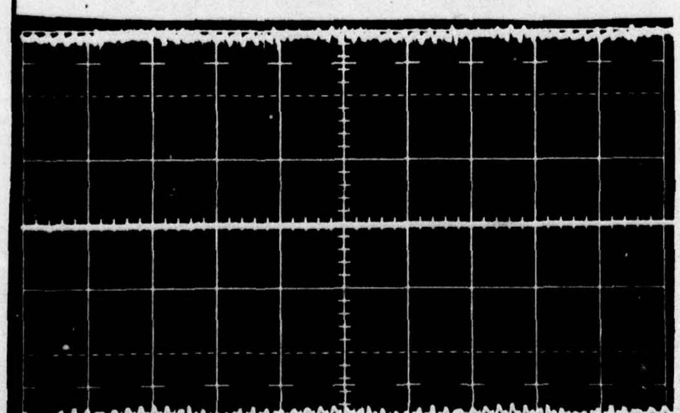
↕ 50A/DIV.

⟷ 2ms/DIV.



0 NEUTRAL CURRENT

FREQUENCY CONVERTER INPUT VOLTAGES



+
0
−

± INPUT VOLTAGES
16KW, PF= 0.8
↕ 50V/DIV.
⟷ 2ms/DIV.

DISTRIBUTION:

INHERENT VOLTAGE DROOP

FREQUENCY CONVERTER OPERATED FROM LABORATORY POWER SUPPLY. THREE PHASE OUTPUTS.

| INPUT VOLTAGE Vdc | INPUT CURRENT Adc | LOAD KW, 0.8PF | OUTPUT VOLTAGE Vrms | FREQ. HZ |
|---|---|---|---|---|
| 281.1 | 6.0 | — | 120.0 | 400 |
| ↓ | 14.0 | 2.2 | 119.4 | ↓ |
| | 21.5 | 4.4 | 118.7 | |
| | 29.0 | 6.6 | 117.8 | |
| | 43.0 | 11.0 | 116.4 | |
| | 58.5 | 16.0 | 113.2 | |
| 286.8 | 1.0 | — | 120 | 60 |
| ↓ | 8.8 | 2.2 | 119.3 | ↓ |
| | 16.5 | 4.4 | 118.6 | |
| | 24.1 | 6.6 | 117.9 | |
| | 39.0 | 11.0 | 117.0 | |
| | 56.7 | 16.0 | 115.7 | |

400Hz VOLTAGE DROOP

$$\frac{120-113.2}{113.2} \times 100 = \underline{\underline{6\%}}$$

60Hz VOLTAGE DROOP

$$\frac{120-115.7}{115.7} \times 100 = \underline{\underline{3.7\%}}$$

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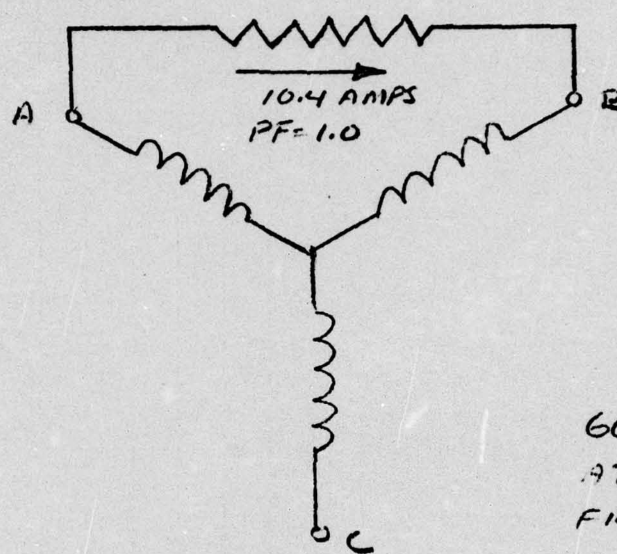
| | | APPROVED | | |

VOLTAGE UNBALANCE WITH UNBALANCED LOAD

FREQUENCY CONVERTER OPERATED FROM LABORATORY POWER SUPPLY.




60 MFD L-T-L AT OUTPUT OF FREQUENCY CONVERTER

| | 400 HZ Vrms | 60 HZ Vrms |
|---|---|---|
| $V_{AB}$ | 208.29 | 208.10 |
| $V_{BC}$ | 209.6 | 209.66 |
| $V_{CA}$ | 211.20 | 210.26 |
| $V_{AN}$ | 121.18 | 120.60 |
| $V_{BN}$ | 120.30 | 120.69 |
| $V_{CN}$ | 121.8 | 121.60 |

400HZ UNBALANCE

$$\frac{211.20-208.29}{208} \times 100 = \underline{1.4\%}$$

60HZ UNBALANCE

$$\frac{210.26-208.1}{208} \times 100 = \underline{1.04\%}$$

DISTRIBUTION:

**DELCO ELECTRONICS**
GENERAL MOTORS CORPORATION

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TITLE

PREPARED CORRY DATE 1/28/74
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APPROVED

EFFICIENCY - FREQUENCY CONVERTER ENERGIZED BY LABORATORY POWER SUPPLY

| FREQ HZ | $V_{IN}$ VDC | $I_{IN}$ ADC | INPUT POWER WATTS | $V_O$ Vrms | $I_P$ Vrms | OUTPUT POWER WATTS | P.F. | LOSSES WATTS | EFF.# % |
|---|---|---|---|---|---|---|---|---|---|
| 400 | 280.5 | 6.0 | 1683 | 119.8 | — | — | — | 1683 | — |
| 400 | 290 | 63.2 | 18328 | 120 | 45.0 | 16200 | 1.0 | 2128 | 88.4 |
| 400 | 291 | 60.0 | 17460 | 116.8 | 56.0 | 15768 | 0.8 | 1692 | 90.3 |
| 60 | 288.1 | 1.0 | 288 | 120.5 | — | — | — | 288 | — |
| 60 | 299 | 57.5 | 17193 | 120.6 | 45.0 | 16268 | 1.0 | 925 | 94.6 |
| 60 | 297.4 | 60 | 17844 | 119.4 | 56.8 | 16133 | 0.8 | 1712 | 90.4 |

# DOES NOT INCLUDE RECTIFIER OR OTHER FIXED LOSSES.

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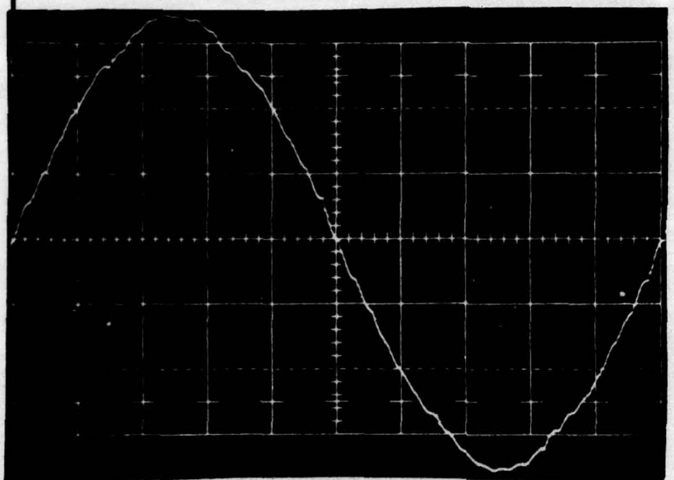
| | | APPROVED | | |

FREQUENCY CONVERTER OUTPUT VOLTAGES

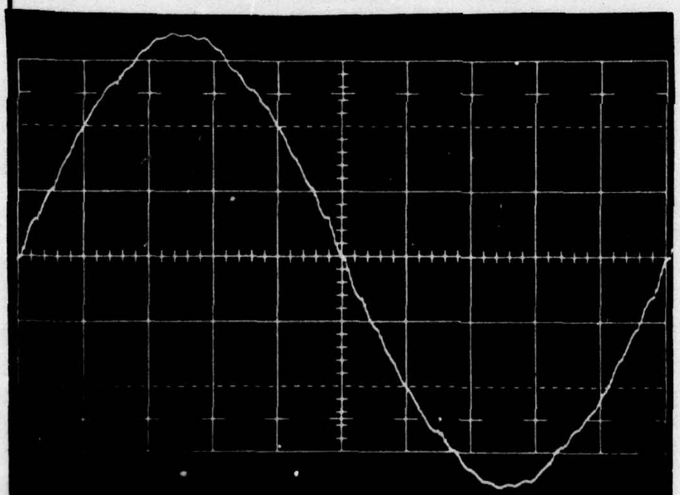


60 HZ THREE PHASE
(NO TRANSISTORS)
(485 MFD L-T-L)

NO LOAD

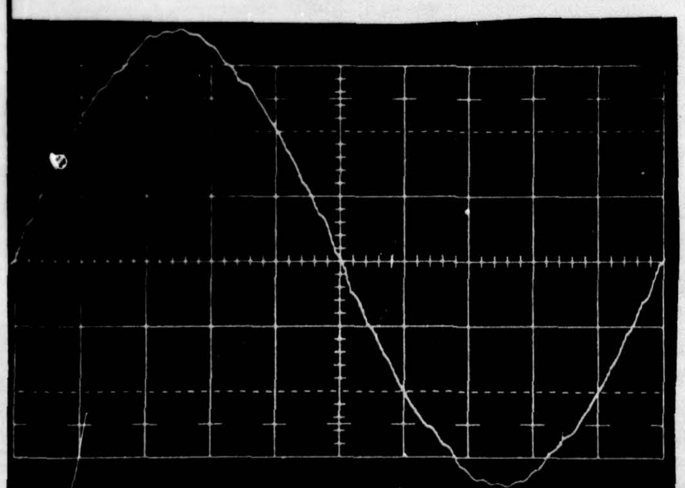
THD = 2 %

50V / DIV



11KW, PF = 1.0

THD = 1.85%



11KW, PF = 0.8

THD = 1.78%

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DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

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| | | DESIGN DATA | 115 |

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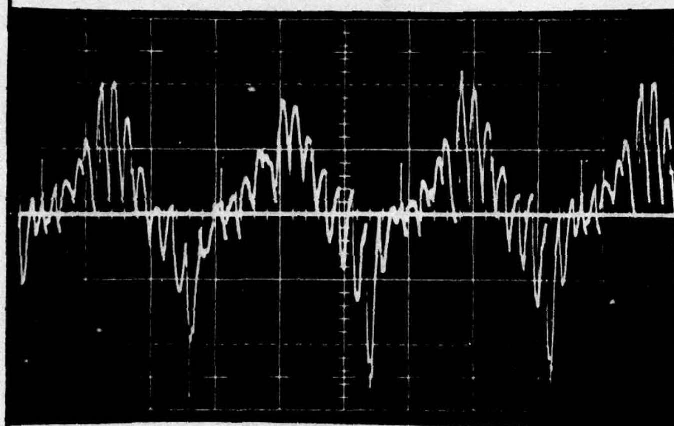
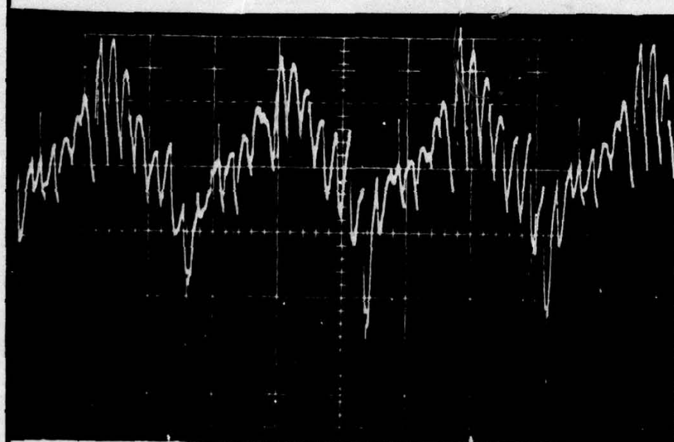
FREQUENCY CONVERTER INPUT CURRENTS

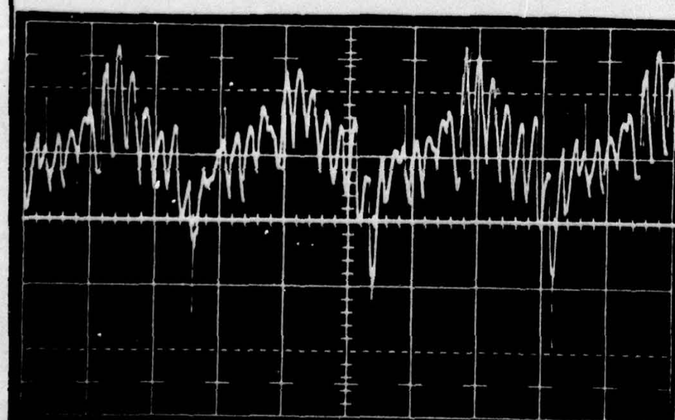


60 HZ THREE PHASE
(NO TRANSISTORS)
(485 MFD L-T-L)
(THREE WIRE INPUT)

DC LINE INPUT CURRENTS
NO LOAD
↕ 40 A/DIV. ⟷ 2MS/DIV.



11KW, PF=1.0



11KW, PF=0.8

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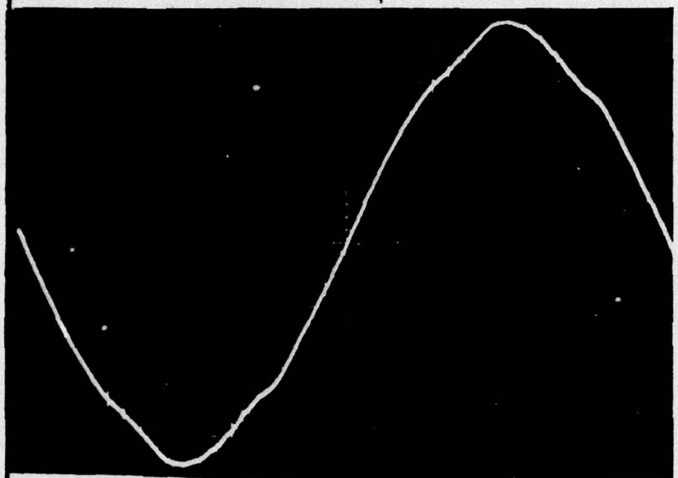
FREQUENCY CONVERTER OUTPUT VOLTAGES

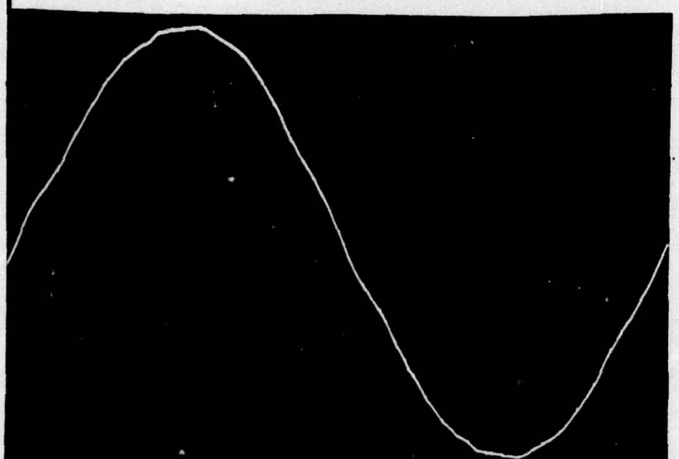


400 HZ SINGLE PHASE
TWO WIRE OUTPUT

NO LOAD

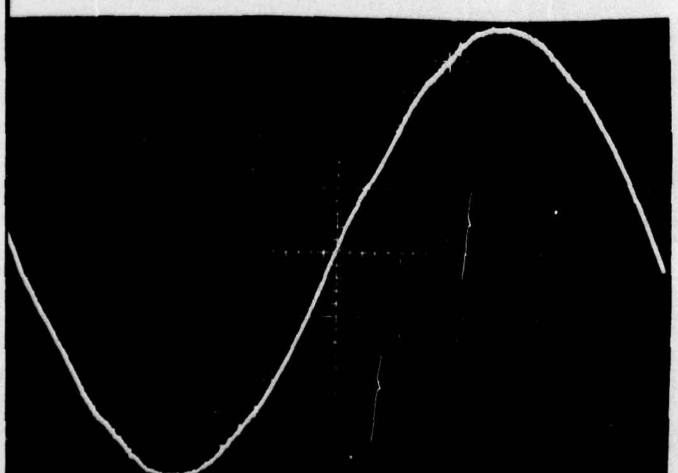
THD = 3.5%

50V/DIV



11KW, PF = 1.0

THD = 2%



11KW, PF = 0.8

THD = 2.1%

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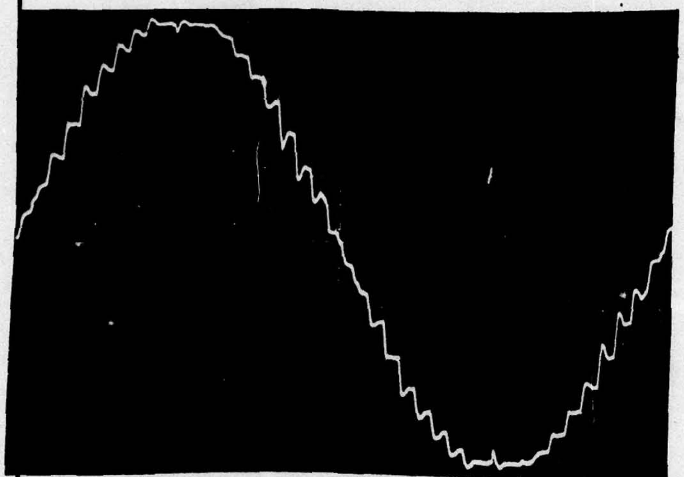
FREQUENCY CONVERTER OUTPUT VOLTAGES

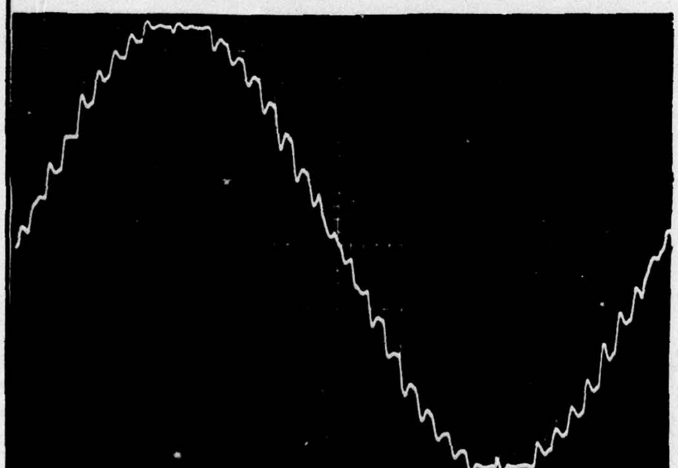


60HZ SINGLE PHASE
TWO WIRE OUTPUT
(WITH TRANSISTORS)
(125MFD L-T-N; 20MFD
PHASE C)

NO LOAD

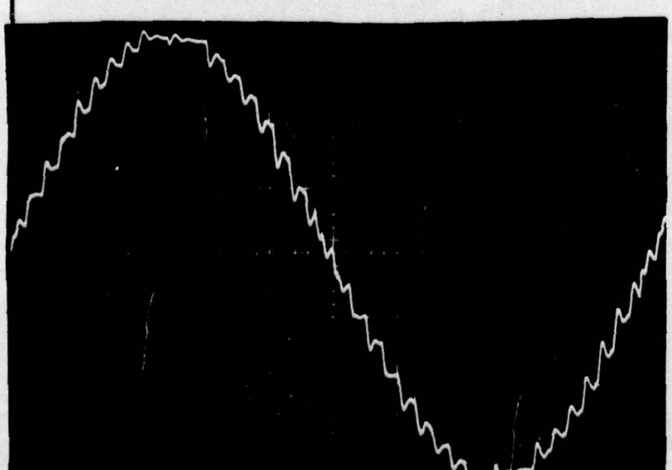
THD= 4.3%

50V/DIV.



11KW, PF=1.0

THD= 4.6%



11KW, PF= 0.8

THD= 4.3%

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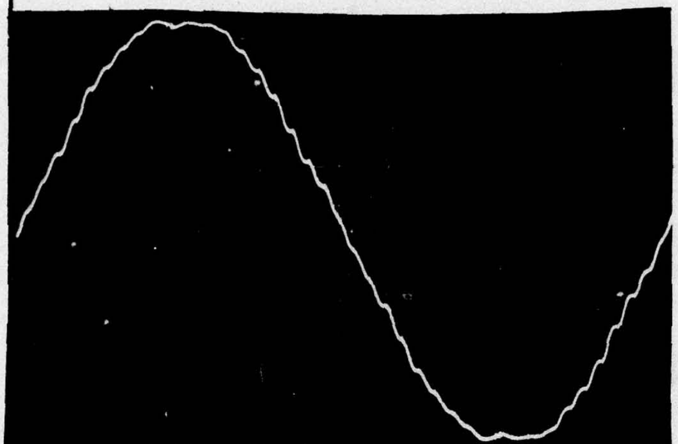
FREQUENCY CONVERTER OUTPUT VOLTAGES & TRANSISTOR CURRENTS

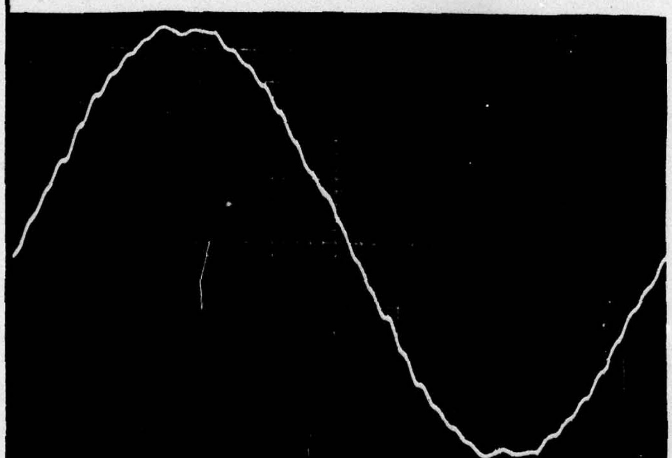


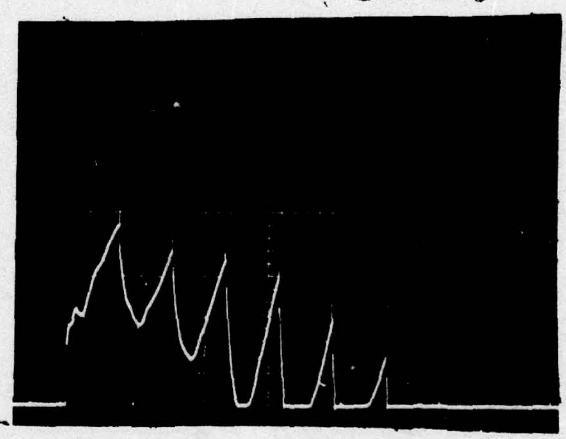
60 HZ SINGLE PHASE
TWO WIRE OUTPUT

(700 MFD L-T-N; 0 MFD PHASE C; 700 MFD A-B)

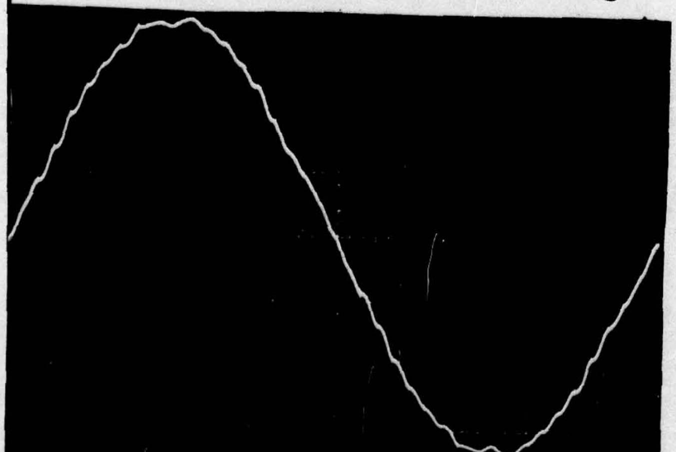
NO LOAD THD= 2.5% 50V/DIV.

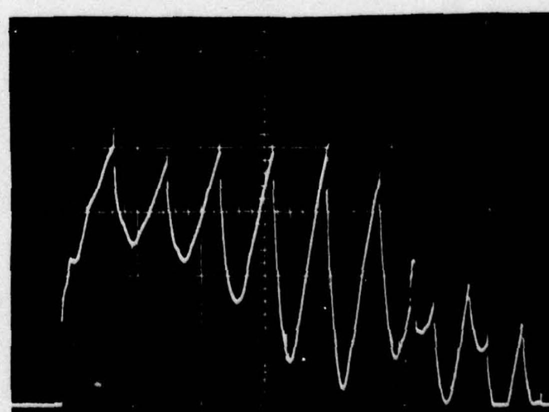
STEP VOLTAGE COMMUTATION
TRANSISTOR CURRENT





16 KW, PF=1.0 THD=2.3%





16KW, PF=1.0 THD=2.42%

25A/DIV. 500 μSEC/DIV.

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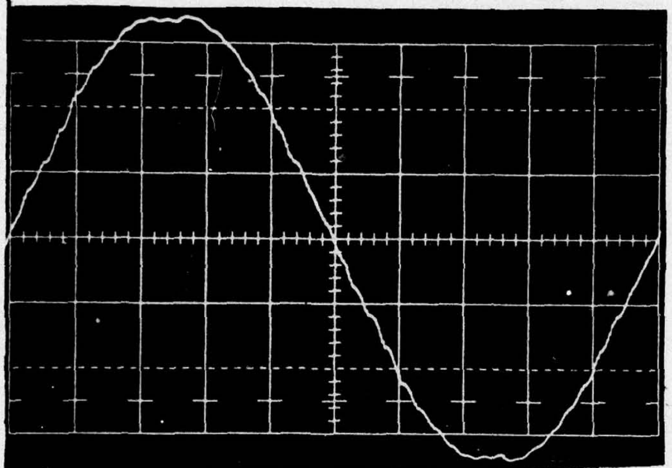
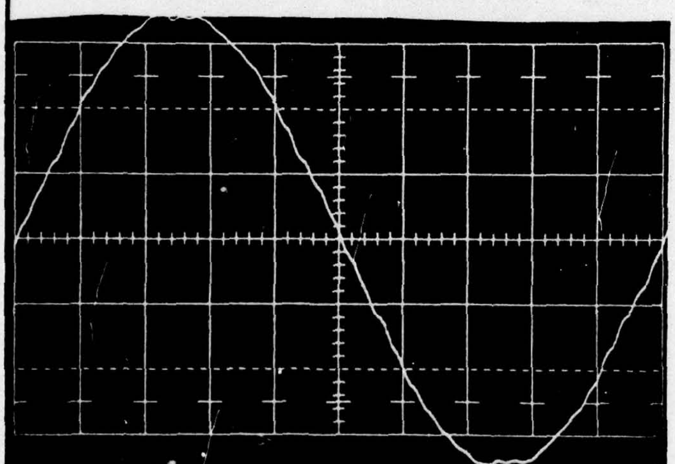
FREQUENCY CONVERTER OUTPUT VOLTAGES



60 HZ SINGLE PHASE
TWO WIRE OUTPUT
(NO TRANSISTORS)
(485 MFD. L-T-L)

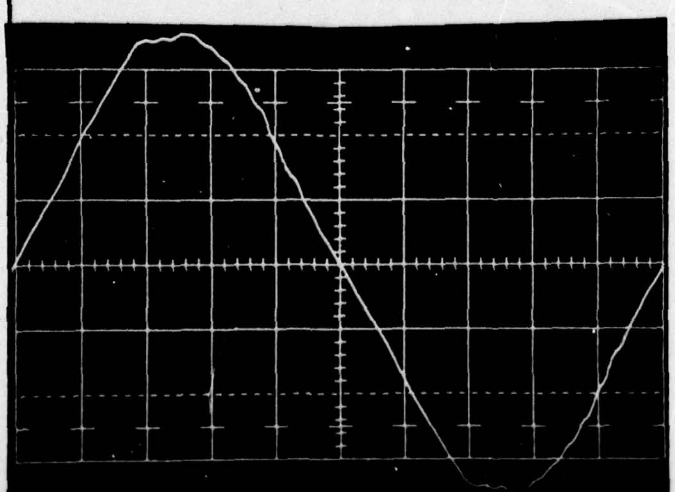
NO LOAD

THD = 2%



11KW, PF = 1.0

THD = 1.8%



11KW, PF = 0.8

THD = 5.2%

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FREQUENCY CONVERTER PORTABLE, ALTERNATING CURRENT MULTIFREQUENC--ETC(U)
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UNCLASSIFIED R74-40-VOL-2 NL

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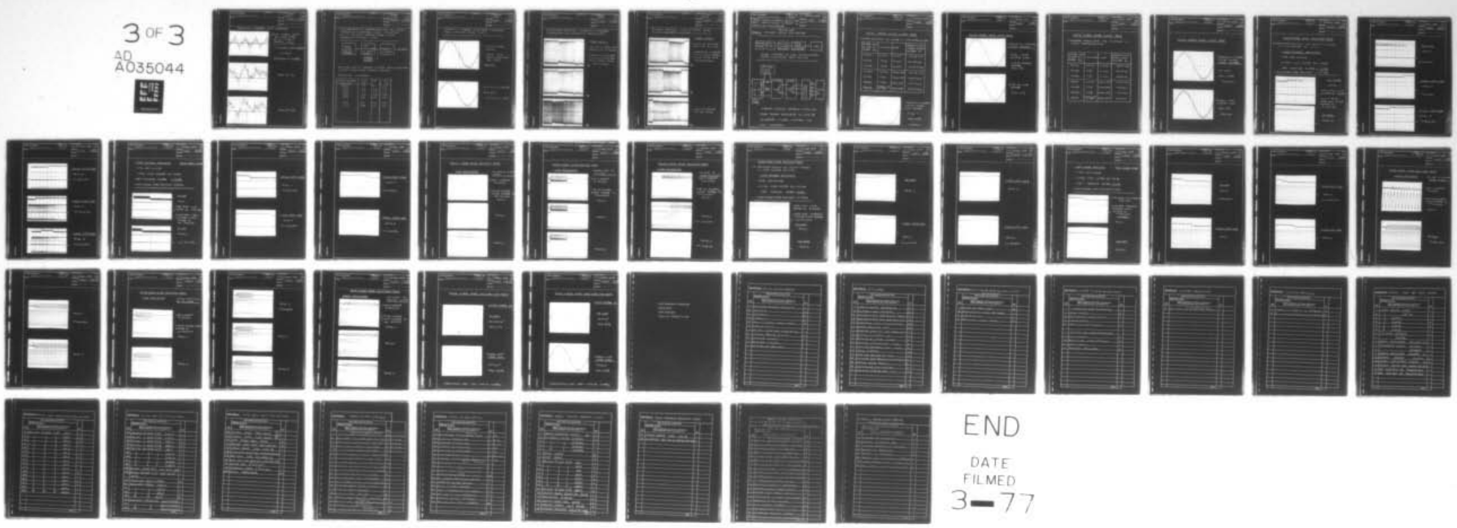
A035044



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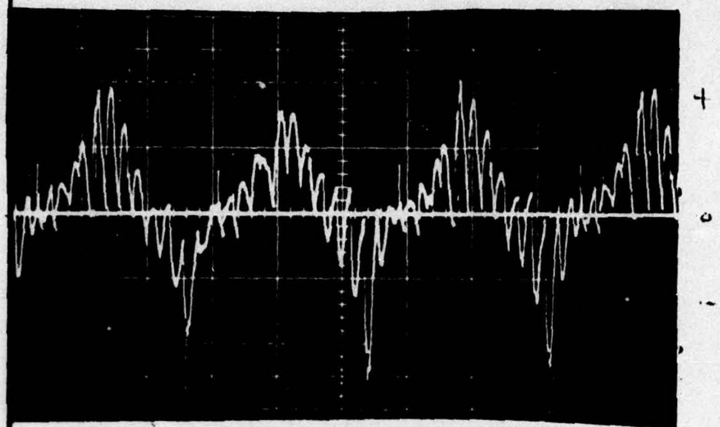
FREQUENCY CONVERTER INPUT CURRENTS

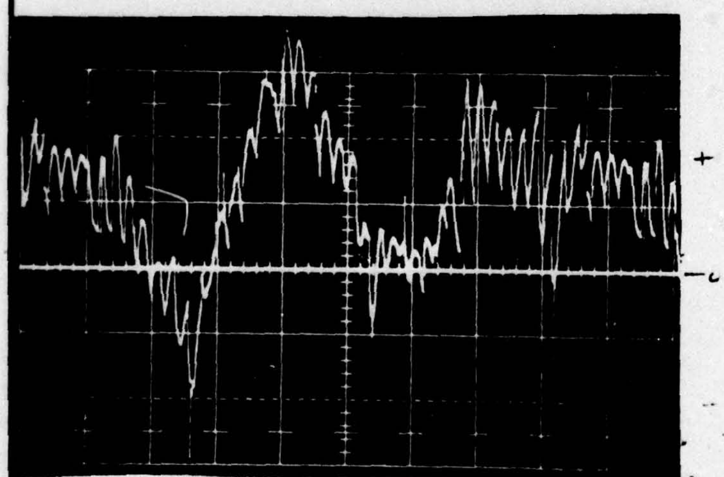


60 HZ SINGLE PHASE
TWO WIRE OUTPUT
(NO TRANSISTORS)
(485 MFD. L-T-L)

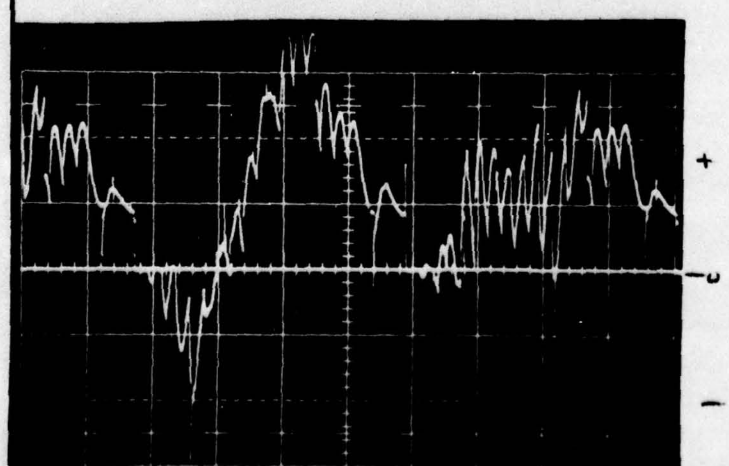
+ DC VOLTAGE INPUT CURRENTS

NO LOAD

↕ 40A/DIV. ← 2ms/DIV.



11KW, PF=1.0



11KW, PF=0.8

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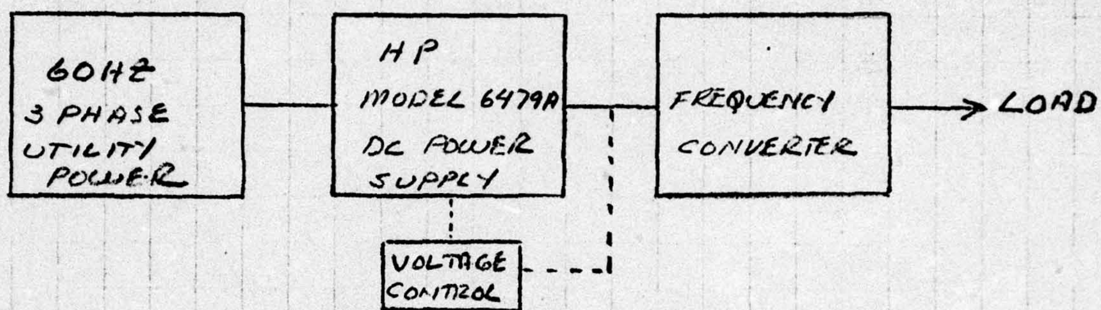
MEASUREMENTS OF PERFORMANCE OF THE MERDC FREQUENCY CONVERTER WHEN ENERGIZED BY A HEWLETT PACKARD MODEL 6479A REGULATED DC POWER SUPPLY




TWO WIRE INPUT TO FREQUENCY CONVERTER, 400HZ, THREE PHASE OUTPUT. (POWER FACTOR CORRECTED CIRCUIT)

FREQUENCY CONVERTER:

| OUTPUT VOLTAGE VOLTS RMS | LOAD KW | PF | THD % |
|---|---|---|---|
| 125.0 | — | — | 2.7 |
| 124.0 | 2.2 | 0.8 | 2.32 |
| 123.3 | 4.4 | 0.8 | 2.07 |
| 122.5 | 6.6 | 0.8 | 1.86 |
| 120.9 | 8.8 | 0.8 | 1.67 |
| | | | |
| 122.7 | 6.6 | 1.0 | 2.35 |
| 119.3 | 8.8 | 1.0 | 2.3 |

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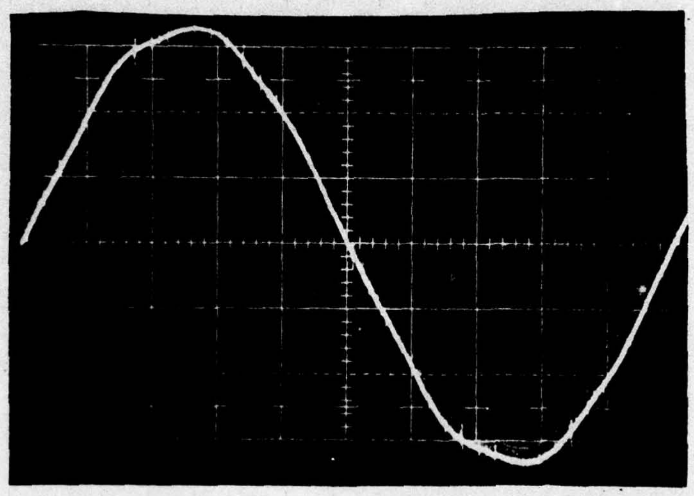
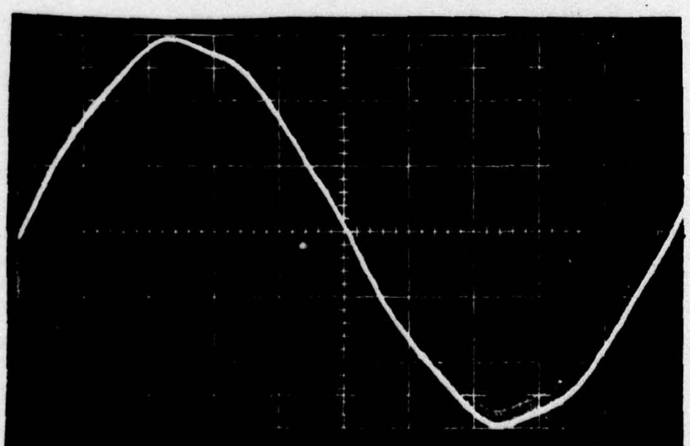
FREQUENCY CONVERTER LOAD TESTS OPERATING FROM HP6479A POWER SUPPLY



LINE-TO-NEUTRAL VOLTAGE

8.8 KW 0.8 PF
400HZ, THREE PHASE
THD = 1.67%

↕ 50 V/DIV.



LINE-TO-LINE VOLTAGE

↕ 100 V/DIV.

SAME LOAD AS ABOVE

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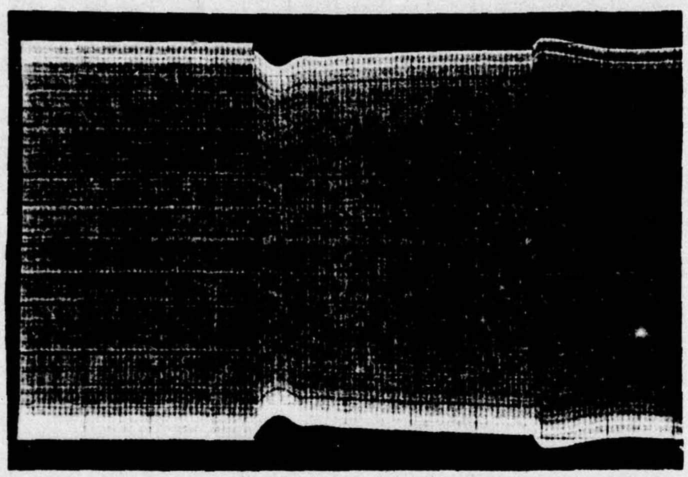
TRANSIENT RESPONSE - FREQUENCY CONVERTER ENERGIZED BY HP 6479A POWER SUPPLY

THREE TRIALS

- NO LOAD TO 8.8KW 0.8PF
- 8.8KW 0.8PF TO NO LOAD

FREQUENCY CONVERTER
L-T-N OUTPUT VOLTAGE
400 HZ, THREE PHASE
↔ 0.2 SEC/DIV.



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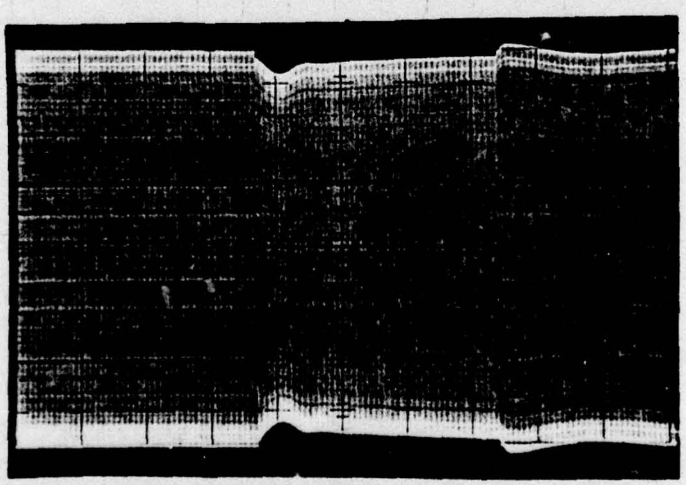

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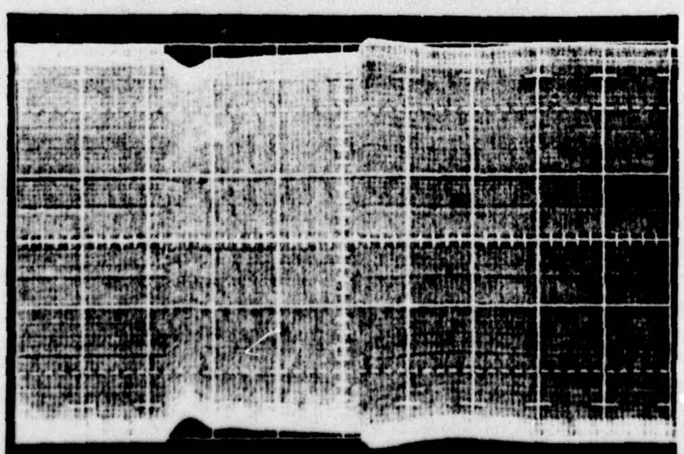

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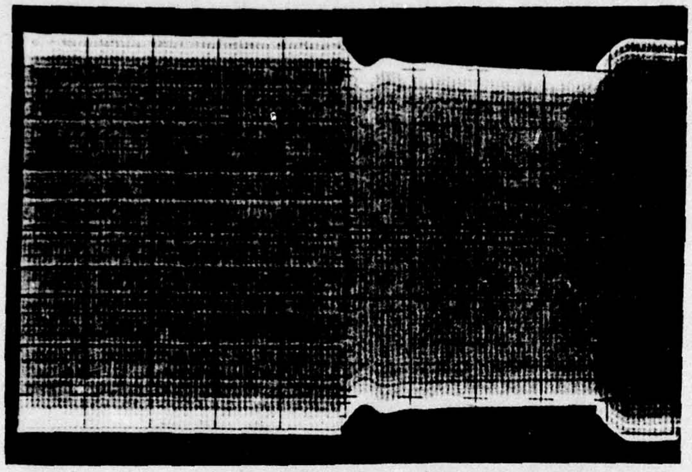
| | APPROVED | |

TRANSIENT RESPONCE - WITH HP 6479A POWER SUPPLY CURRENT LIMITING

THREE TRIALS

- NO LOAD TO 11KW 0.8PF
- 11KW 0.8PF TO NO LOAD

FREQUENCY CONVERTER
L-T-N OUTPUT VOLTAGE
400HZ, THREE PHASE
⟷ 0.2SEC/DIV.



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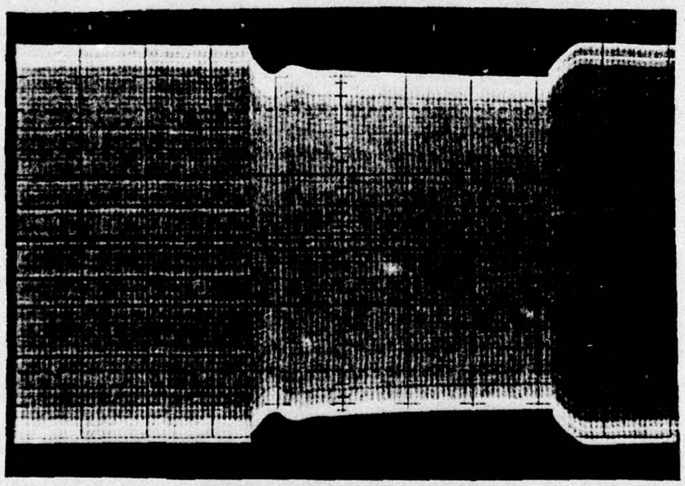
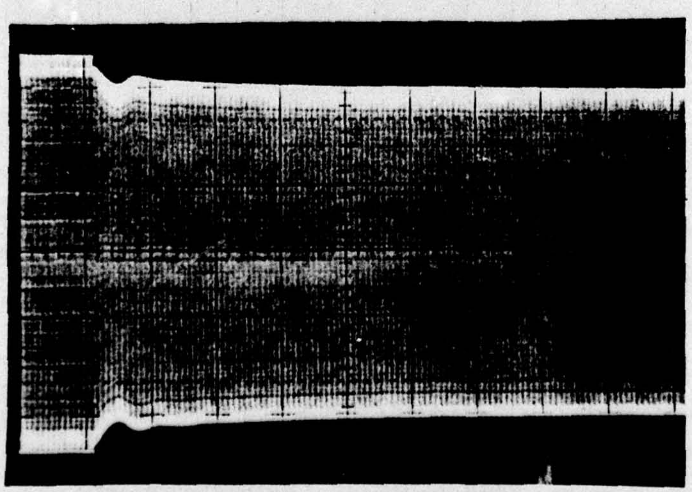


②



LOAD NOT REMOVED
FOR THIS TRIAL

③

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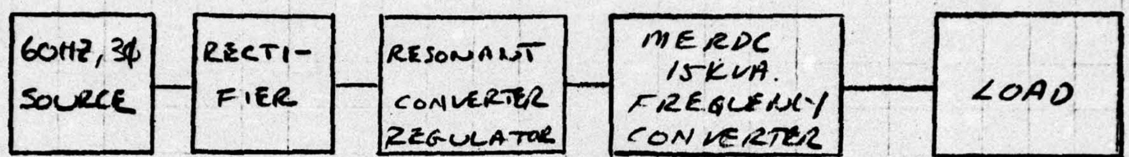
ITEM NO. 0005

TASK 3 PERFORM DESIGN DATA TESTING




BLOCK DIAGRAM OF THE EXPERIMENTAL POWER CONDITIONER TEST SET-UP

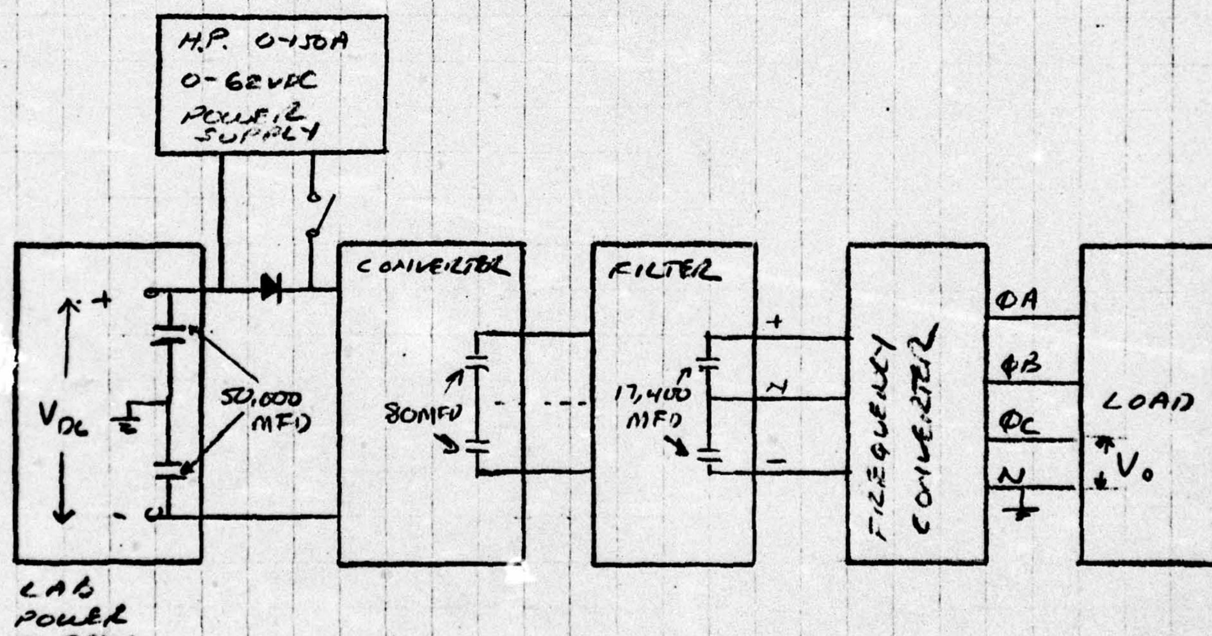


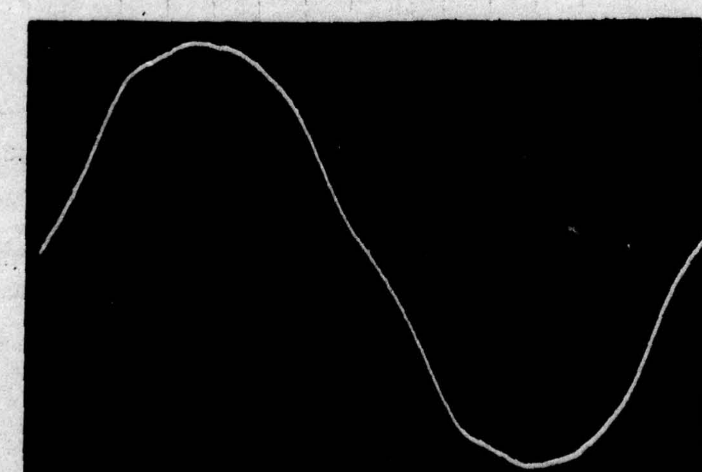

DIAGRAM SHOWING METHOD OF APPLYING POWER SOURCE TRANSIENTS TO INPUT OF CONVERTER. FILTER CAPACITORS ARE ALSO IDENTIFIED

DISTRIBUTION:

400 Hz, THREE PHASE OUTPUT TESTS

1) VOLTAGE REGULATION FOR CHANGES IN INPUT VOLTAGE & LOAD

| VOLTAGE INPUT TO REG. CONVERTER Vdc | CONDITION | LOAD | FREQUENCY CONVERTER OUTPUT VOLTAGE $V_o$ |
|---|---|---|---|
| 340 Vdc | NORMAL | NO LOAD | 120.66 Vrms |
| 374 Vdc | +10% | NO LOAD | 120.69 Vrms |
| 289 Vdc | -15% | NO LOAD | 120.61 Vrms |
| 340 Vdc | NORMAL | 13.2 KW, 0.8 PF | 120.08 Vrms |
| 374 Vdc | +10% | 13.2 KW, 0.8 PF | 120.09 Vrms |
| 289 Vdc | -15% | 13.2 KW, 0.8 PF | 120.07 Vrms |
| 268 Vdc | LOWER LIMIT OF REG. | 13.2 KW, 0.8 PF | 120.06 Vrms |



FREQUENCY CONVERTER LINE-TO-NEUTRAL OUTPUT VOLTAGE

NO LOAD

THD = 3.95%

120.66 Vrms

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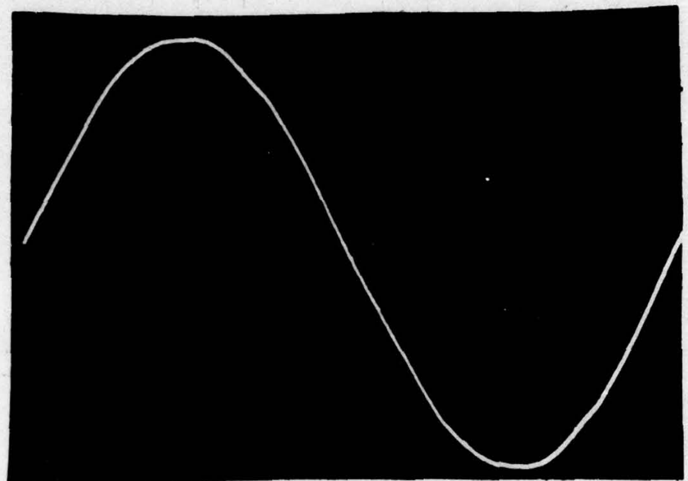
|---|---|

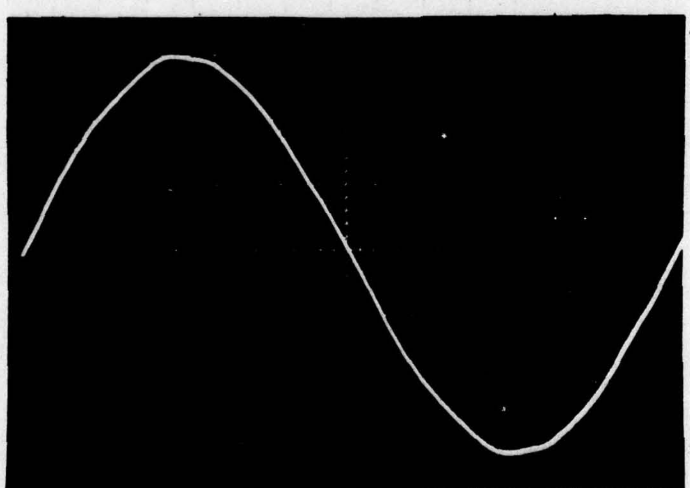
## 400 HZ, THREE PHASE OUTPUT TESTS

FREQUENCY CONVERTER OUTPUT VOLTAGES



13.2KW, 0.8PF
16.5KVA LOAD

LINE-TO-NEUTRAL VOLTAGE
THD= 1.1%



LINE-TO-LINE VOLTAGE

THD= 1.1%

DISTRIBUTION:

## 60 HZ, THREE PHASE OUTPUT TESTS

1) VOLTAGE REGULATION FOR CHANGES IN INPUT VOLTAGE & LOAD.

| VOLTAGE INPUT TO REG. CONVERTER $V_{DC}$ | CONDITION | LOAD | FREQUENCY CONVERTER OUTPUT VOLTAGE $V_0$ |
|---|---|---|---|
| 340 Vdc | NORMAL | NO LOAD | 120.4 Vrms |
| 374 Vdc | +10% | NO LOAD | 120.5 Vrms |
| 289 Vdc | -15% | NO LOAD | 120.3 Vrms |
| 340 Vdc | NORMAL | 13.2 KW, 0.8 PF | 120.2 Vrms |
| 374 Vdc | +10% | 13.2 KW, 0.8 PF | 118.96 Vrms |
| 289 Vdc | -15% | 13.2 KW, 0.8 PF | 120.1 Vrms |
| 260 Vdc | LOWER LIMIT OF REG. | 13.2 KW, 0.8 PF | 120.0 Vrms |

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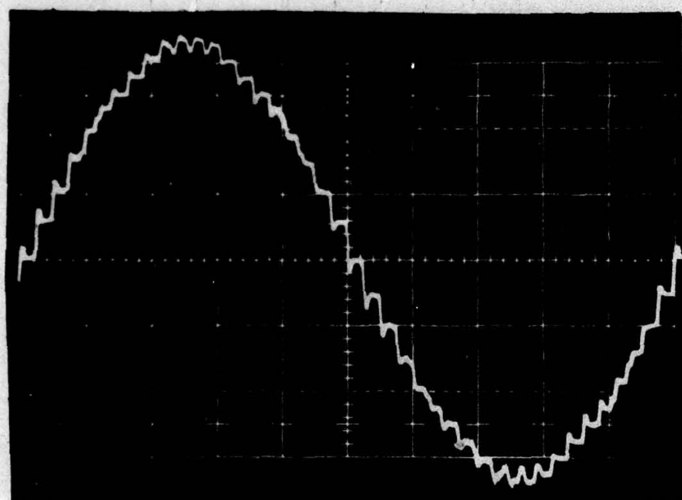
| | | APPROVED | | |

## 60 HZ, THREE PHASE OUTPUT TESTS

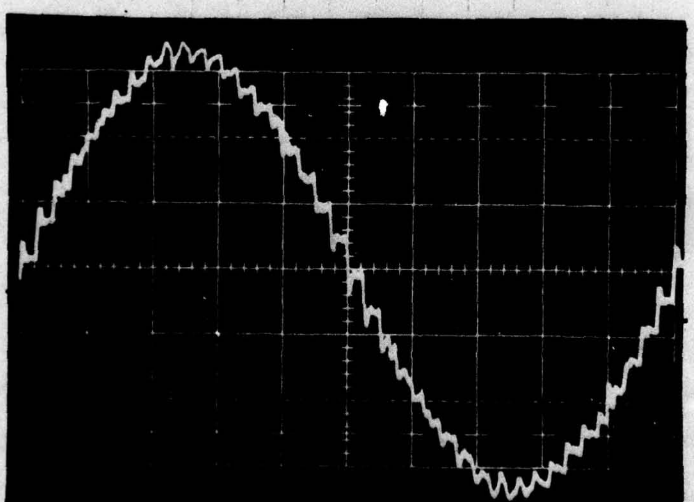


FREQUENCY CONVERTER LINE-TO-NEUTRAL OUTPUT VOLTAGES

NO LOAD

THD= 4.54%

120.4 Vrms



13.2KW, 0.8PF
16.5KVA LOAD

THD= 5%

120.2 Vrms

DISTRIBUTION:

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## 400HZ, THREE PHASE TRANSIENT TESTS

2) TRANSIENT RESPONSE FOR ABRUPT CHANGES IN INPUT VOLTAGE OR LOAD.

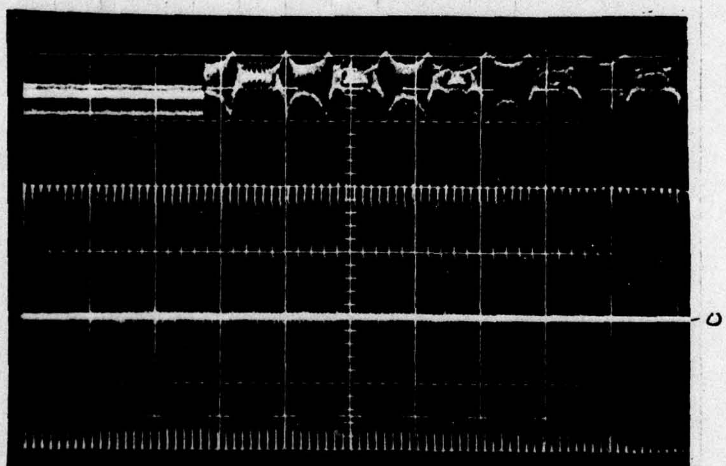
### INPUT VOLTAGE TRANSIENTS

+10% STEP CHANGE

INITIAL INPUT VOLTAGE $V_{DC}$ = 340 Vdc

STEP INCREASE VOLTAGE = 34 Vdc

INPUT VOLTAGE AFTER TRANSIENT = 374 Vdc

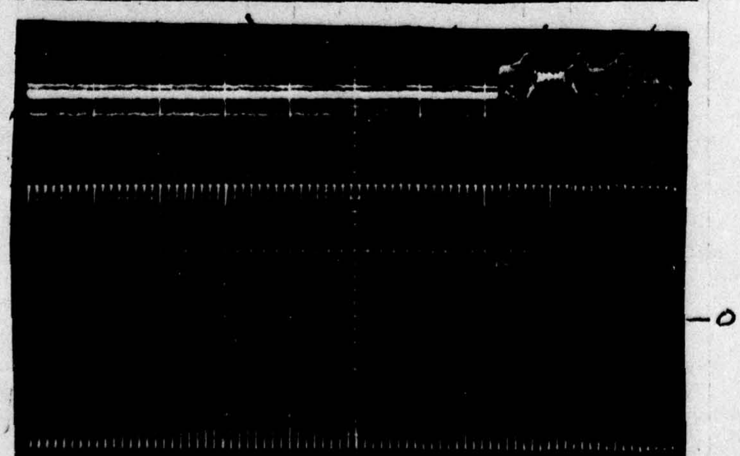



NO LOAD

TRIAL 1

UPPER TRACE - INPUT VOLTAGE $V_{DC}$ ↕100V/DIV.

LOWER TRACE - FREQ. CONV. OUTPUT VOLTAGE $V_0$ ↔ 20MS/DIV.




NO LOAD

TRIAL 2

DISTRIBUTION:

DE 255 REV. 12-66

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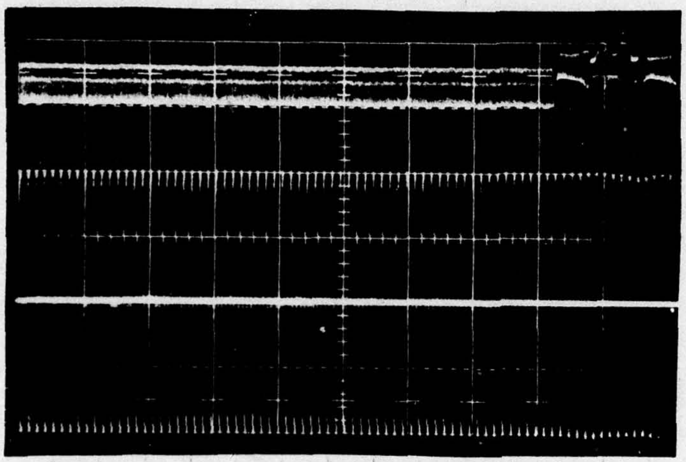
| | APPROVED | |

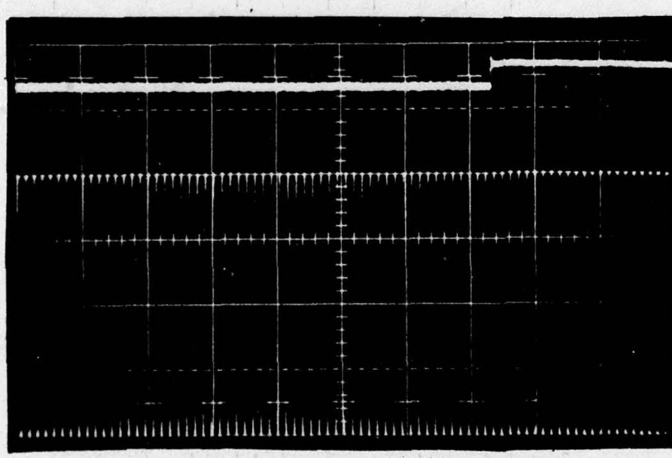


2KW LOAD

TRIAL 3

0

↔ 20 ms / DIV.

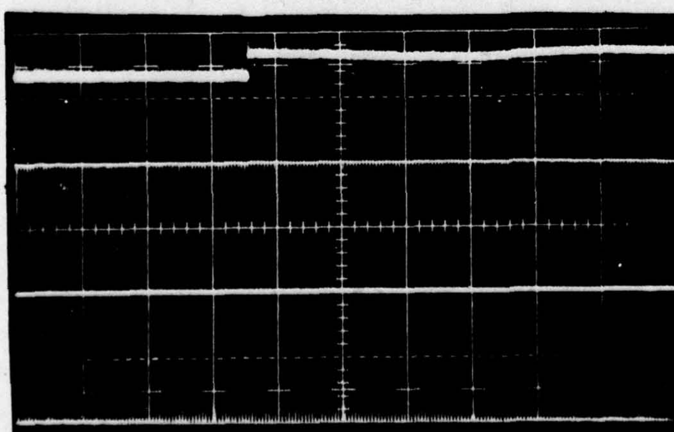


13.2KW, 0.8PF LOAD

TRIAL 4

-0

↔ 20MS./DIV.



13.2KW, 0.8PF LOAD

TRIAL 5

-0

↔ 50 MS / DIV.

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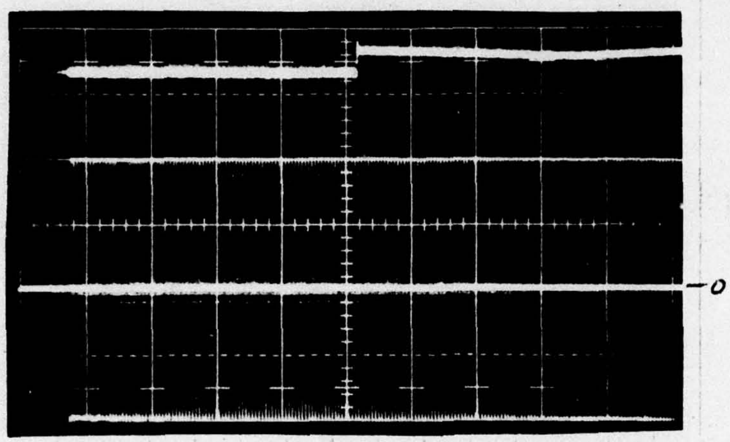
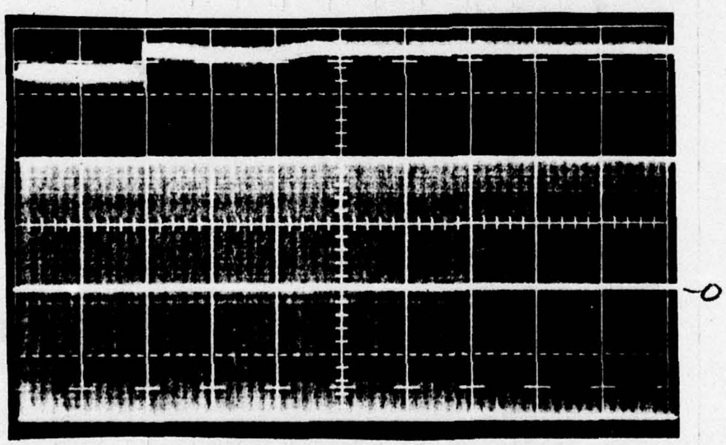



13.2 KW, 0.8 PF LOAD

TRIAL 6

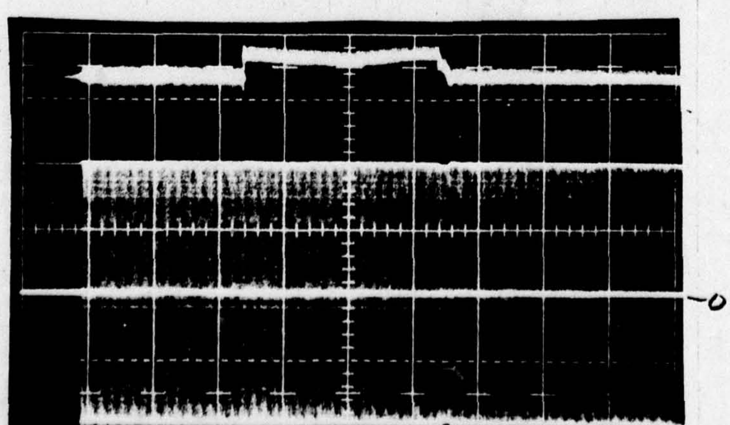
↔ 50MS / DIV




13.2KW, 0.8 PF LOAD

TRIAL 7

↔ 100MS / DIV.




13.2KW, 0.8 PF LOAD

TRIAL 8

↔ 100MS / DIV.

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| | | APPROVED | | |

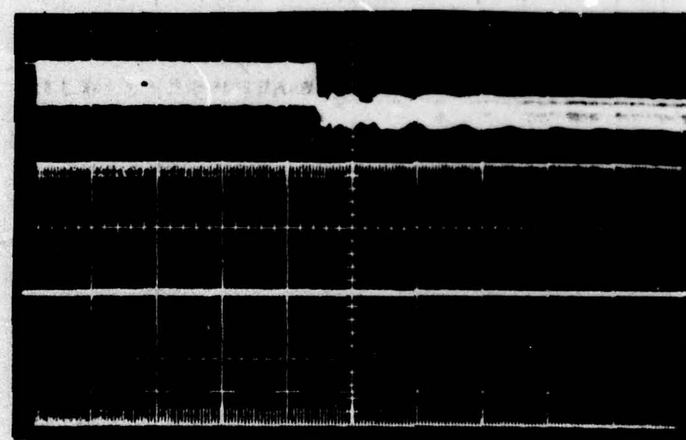
INPUT VOLTAGE TRANSIENTS — 400 HZ, THREE PHASE

−15% STEP CHANGE

INITIAL INPUT VOLTAGE $V_{DC}$ = 340 Vdc

STEP DECREASE VOLTAGE = −57 Vdc

INPUT VOLTAGE AFTER TRANSIENT = 289 Vdc



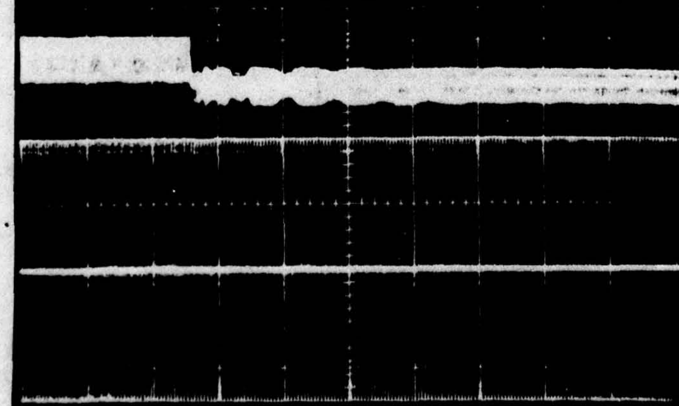
0

NO LOAD

TRIAL 1

UPPER TRACE – INPUT VOLTAGE $V_{DC}$ ↕ 100V/DIV

LOWER TRACE – FREQ. CONVERTER OUTPUT VOLTAGE $V_o$ ↔ 50 ms/DIV.



0

NO LOAD

TRIAL 2

↔ 50 ms/DIV.

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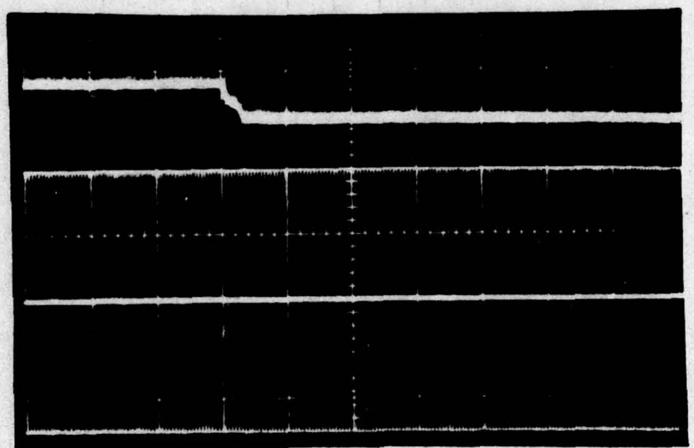
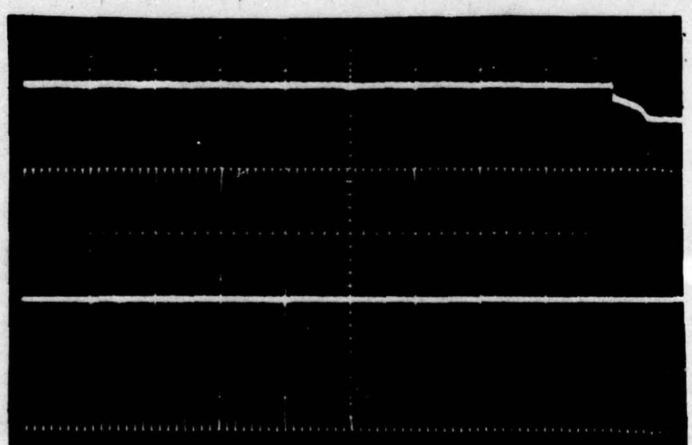
| | | APPROVED | | |



13.2 KW, 0.8 PF LOAD

TRIAL 3

↔ 50 ms/DIV



13.2KW, 0.8 PF LOAD

TRIAL 4

↔ 20MS/DIV.

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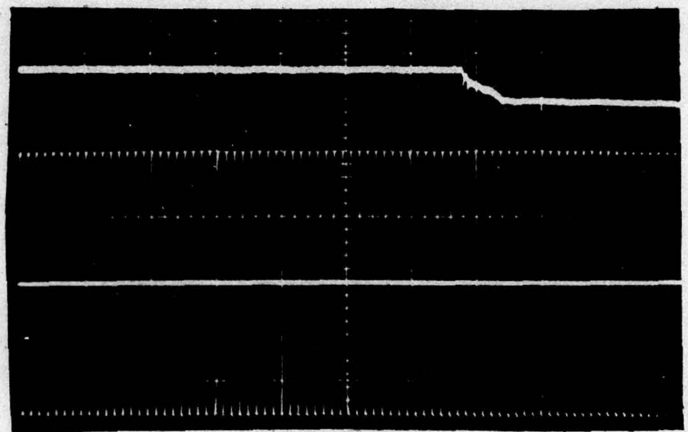
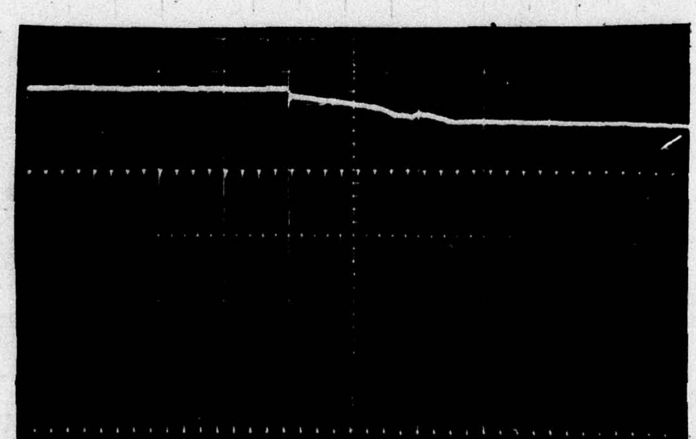


13.2KW, 0.8PF LOAD

TRIAL 5

↔ 20MS/DIV.



13.2KW, 0.8PF LOAD

TRIAL 6

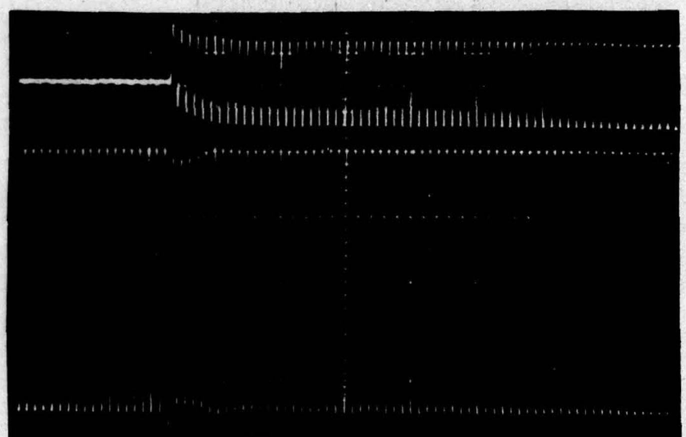
↔ 10MS/DIV.

DISTRIBUTION:

# 400 HZ, THREE PHASE TRANSIENT TESTS

## LOAD TRANSIENTS

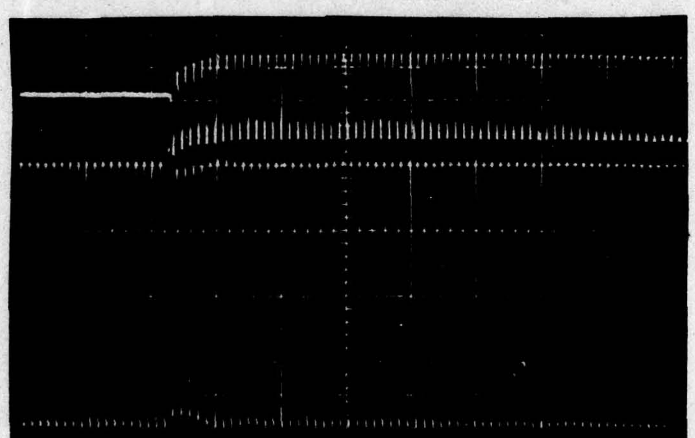
NO LOAD TO 13.2KW 0.8PF



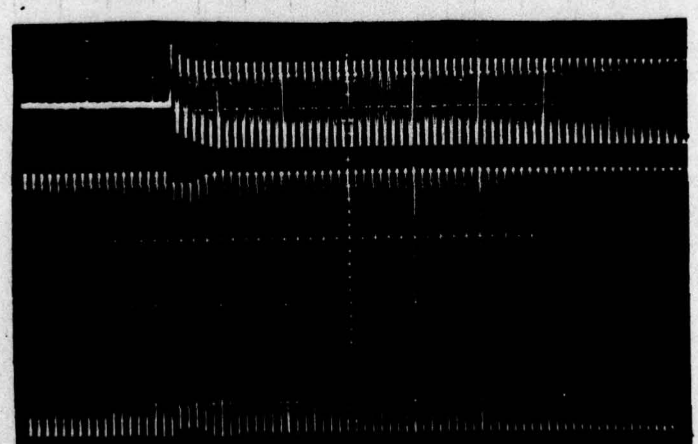
LOAD CURRENT
↕ 100A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE $V_o$
⟷ 20MS/DIV

TRIAL 1



TRIAL 2



TRIAL 3

DISTRIBUTION:

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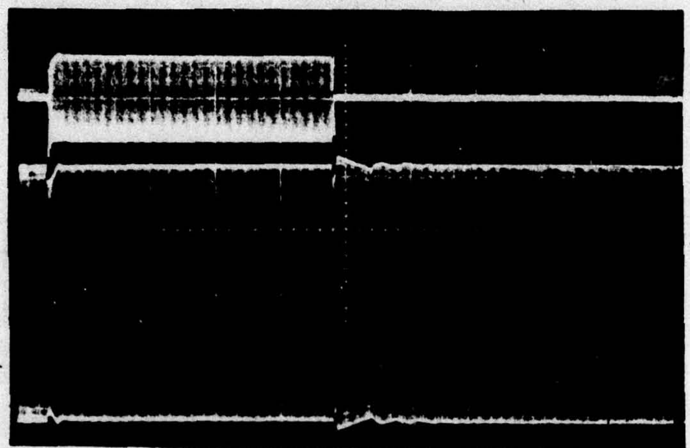
400 HZ, THREE PHASE TRANSIENT TESTS

LOAD TRANSIENTS

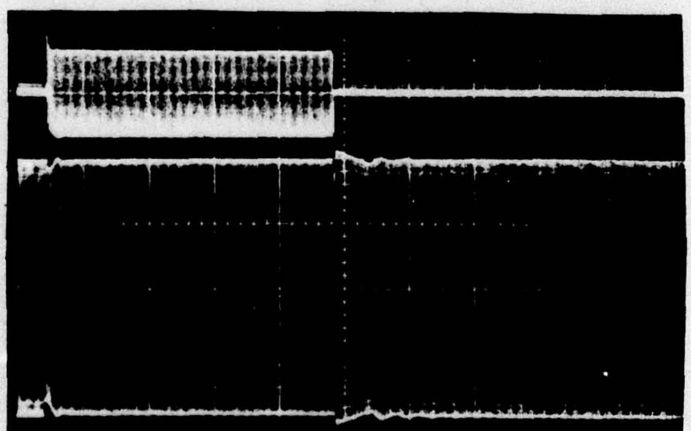
13.2KW, 0.8PF TO NO LOAD



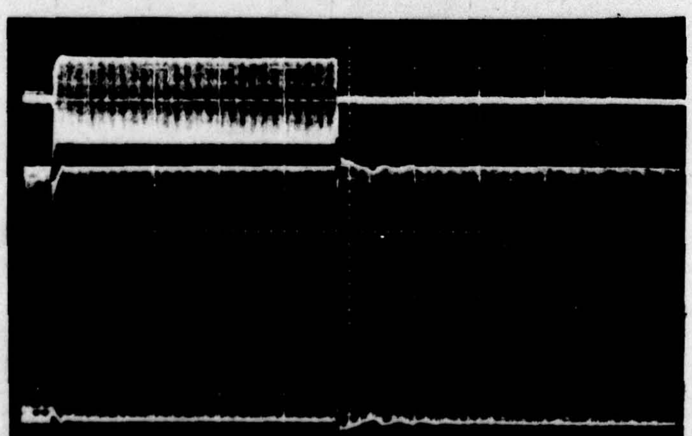
LOAD CURRENT ↕ 100A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE $V_o$ ↔ 20ms/DIV.

TRIAL 1



TRIAL 2



TRIAL 3

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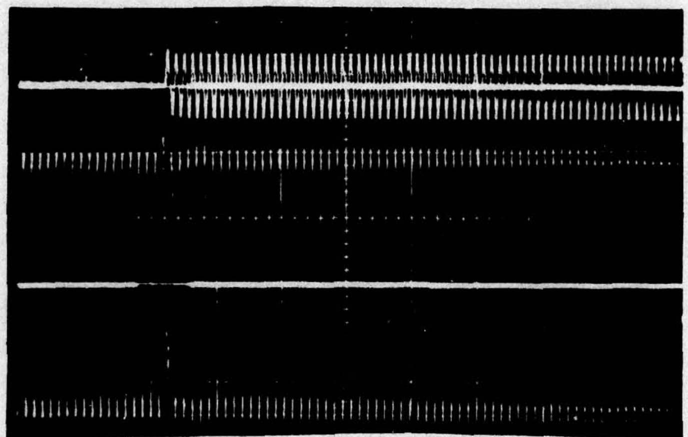
| | | APPROVED | | |

400 HZ, THREE PHASE TRANSIENT TESTS

LOAD TRANSIENTS



NO LOAD TO TWO P.U., 0.4PF

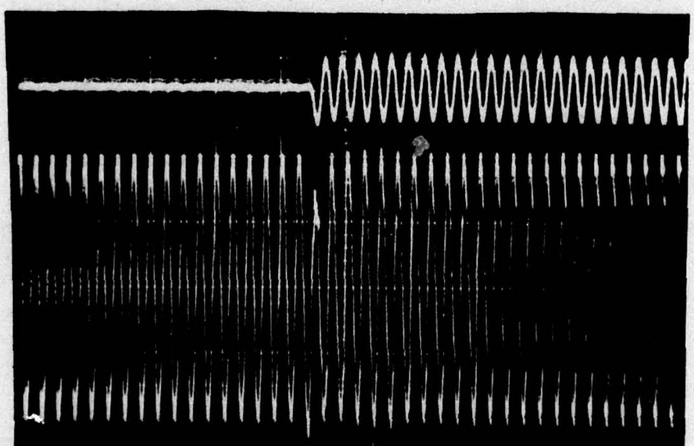
LOAD CURRENT

↕ 200 A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE Vo

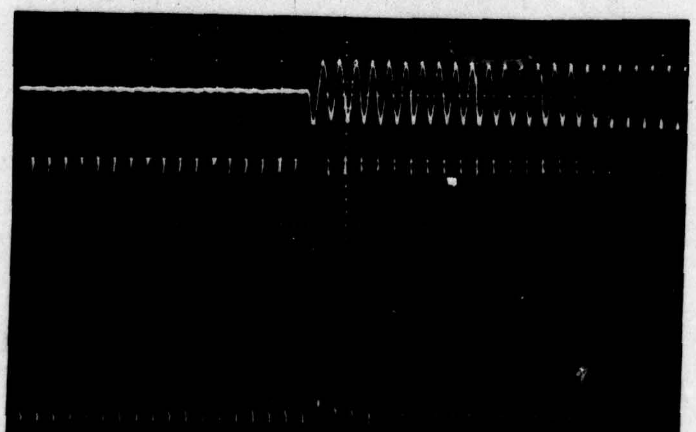
↔ 20MS/DIV.

TRIAL 1



TRIAL 2

↔ 10MS/DIV.



TRIAL 3

↔ 10MS/DIV.

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60HZ, THREE PHASE TRANSIENT TESTS

2) TRANSIENT RESPONSE FOR ABRUPT CHANGES IN INPUT VOLTAGE OR LOAD.

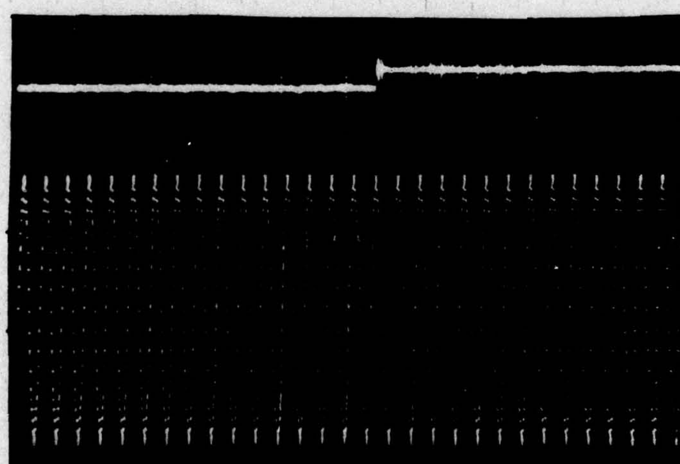
INPUT VOLTAGE TRANSIENTS

+10% STEP CHANGE

INITIAL INPUT VOLTAGE $V_{DC}$ = 340 Vdc

STEP INCREASE VOLTAGE = 34 Vdc

INPUT VOLTAGE AFTER TRANSIENT = 374 Vdc



–0

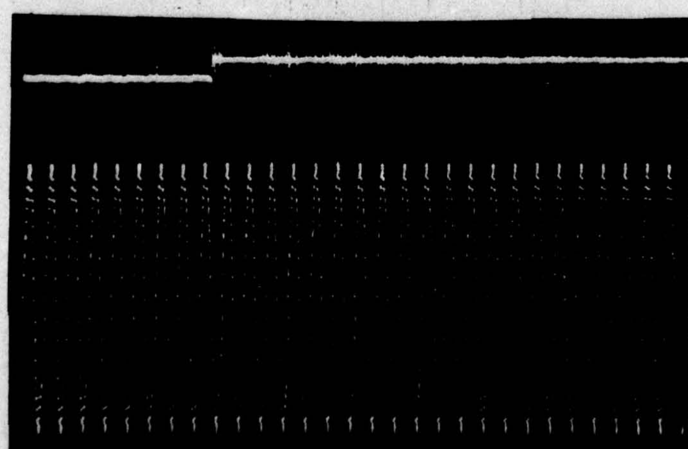
UPPER TRACE - INPUT VOLTAGE $V_{DC}$ ↕ 100V/DIV.

LOWER TRACE - FREQUENCY CONVERTER OUTPUT VOLTAGE $V_c$

↔ 50ms/DIV.

NO LOAD

TRIAL 1



–0

NO LOAD

TRIAL 2

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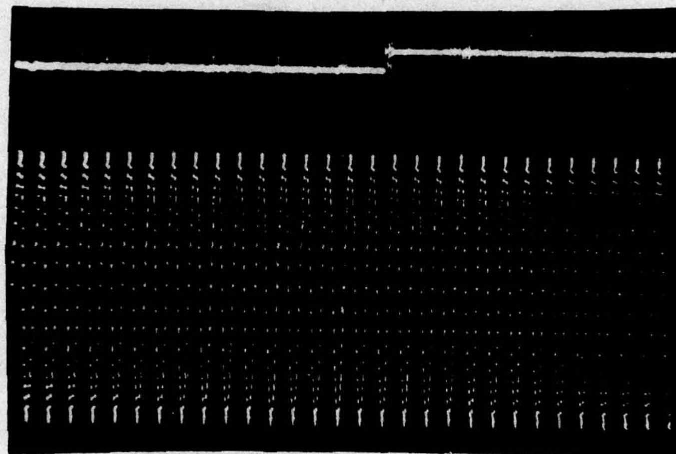
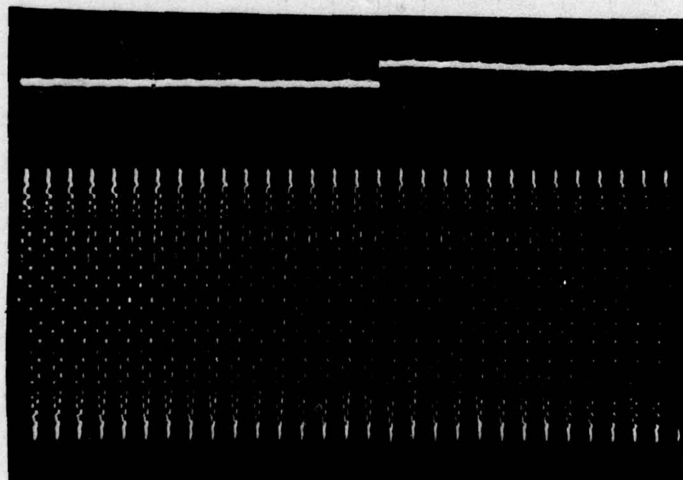


-0

NO LOAD

TRIAL 3



-0

13.2KW, 0.8 PF LOAD

TRIAL 1

⟷ 50 ms/DIV.

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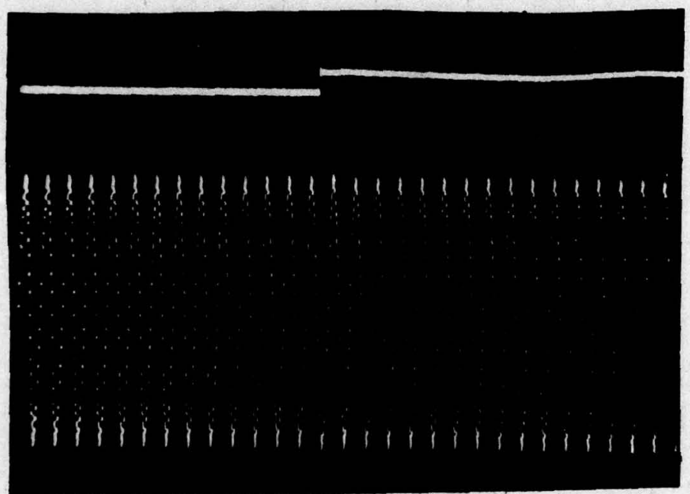
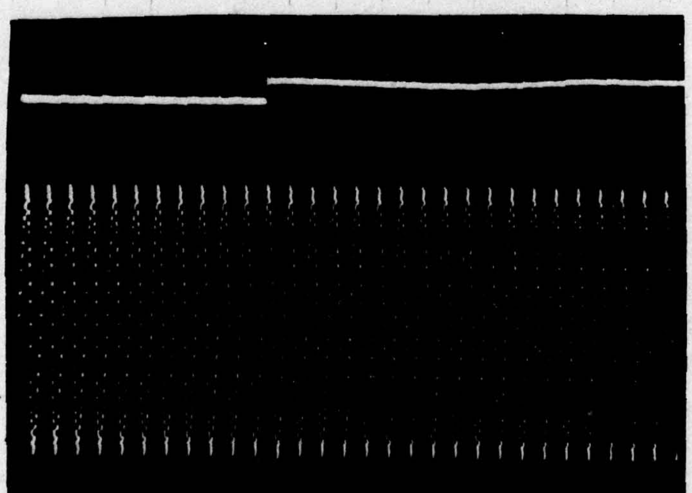


13.2 KW, 0.8 PF LOAD

TRIAL 2



13.2 KW, 0.8 PF LOAD

TRIAL 3

↔ 50 MS/DIV.

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| | | APPROVED | | |

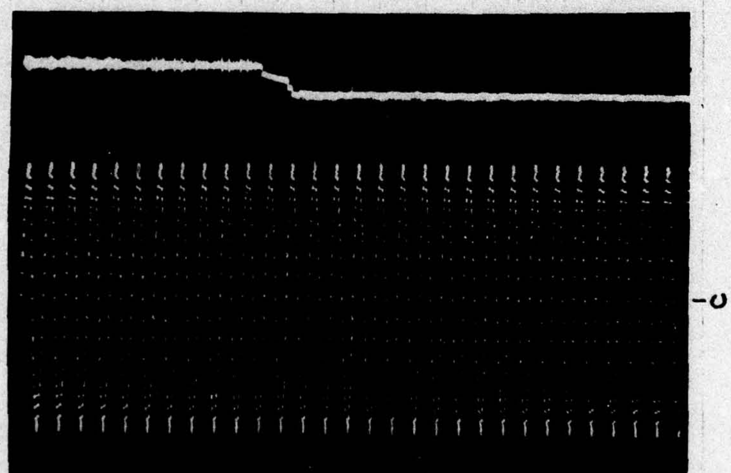
INPUT VOLTAGE TRANSIENTS 60HZ, THREE PHASE

-15% STEP CHANGE

INITIAL INPUT VOLTAGE $V_{DC}$ = 340 $V_{dc}$

STEP DECREASE VOLTAGE = -51 $V_{dc}$

INPUT VOLTAGE AFTER TRANSIENT = 289 $V_{dc}$

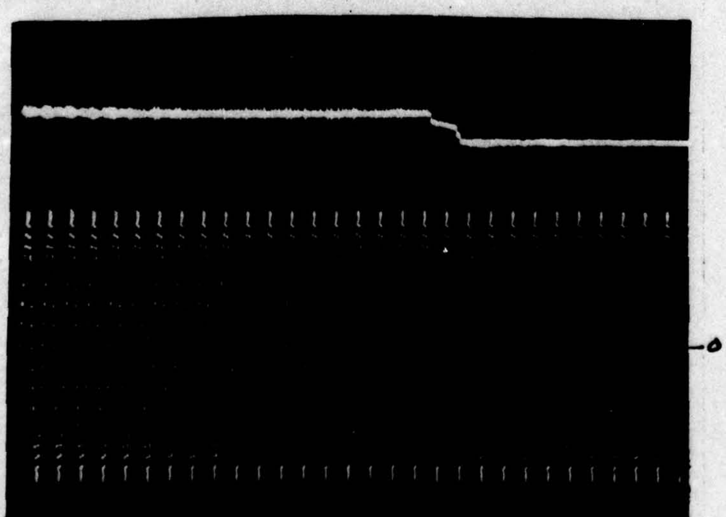



UPPER TRACE - INPUT VOLTAGE $V_{DC}$
↕ 100 V/DIV.

LOWER TRACE - FREQUENCY CONVERTER OUTPUT VOLTAGE $V_o$
↔ 50mS/DIV.

NO LOAD

TRIAL 1




NO LOAD

TRIAL 2

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DE 255 REV. 12-66

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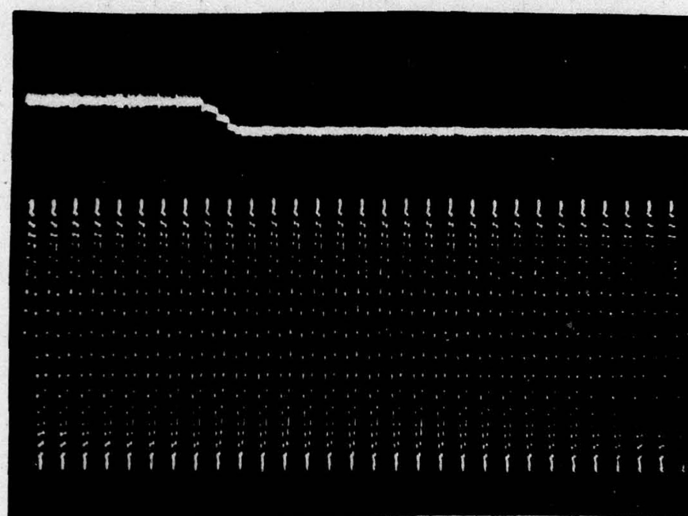
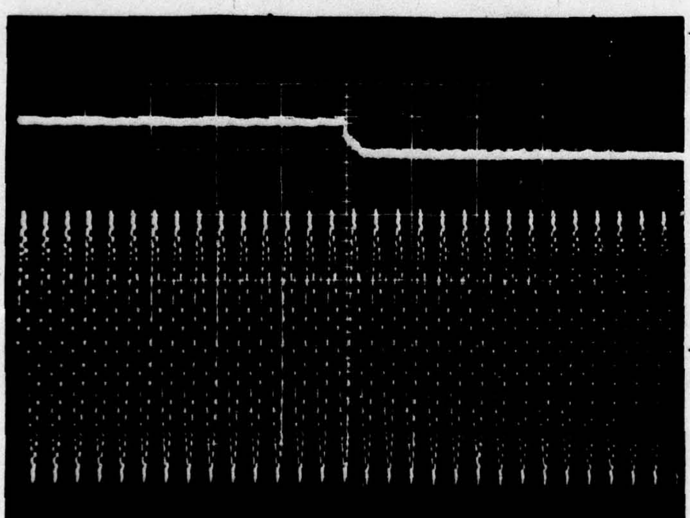


NO LOAD

TRIAL 3

←→ 50 ms/DIV.



13.2 KW, 0.8 PF LOAD

TRIAL 1

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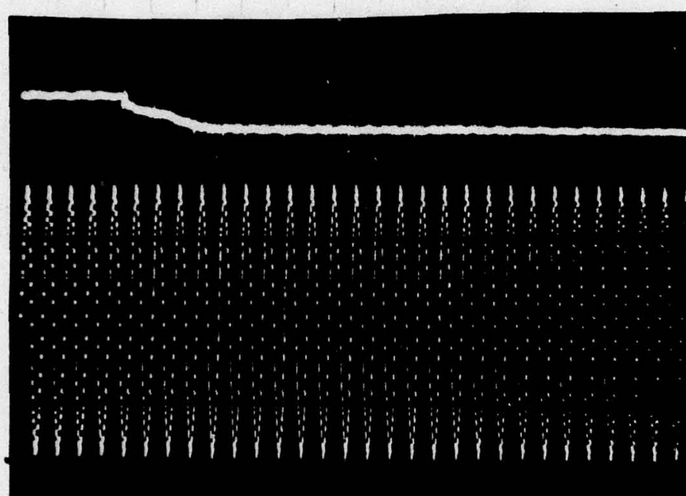
| | | CHECKED | | |
| | | APPROVED | | |

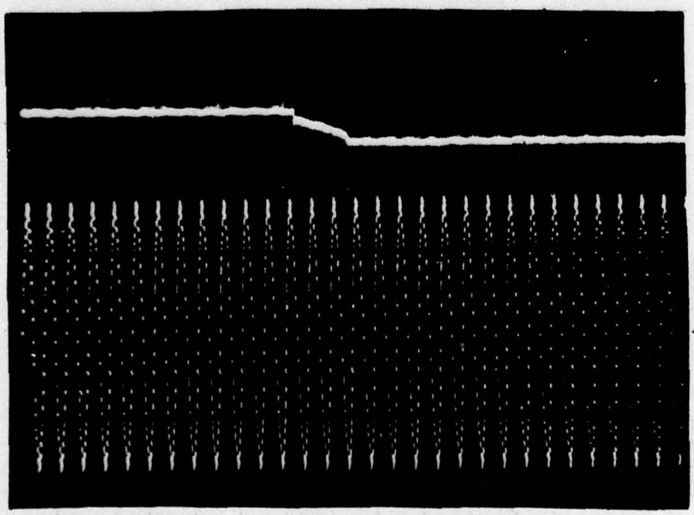


-0

13.2KW, 0.8PF LOAD

TRIAL 2

↔ 50 MS/DIV.



-0

13.2KW, 0.8PF LOAD

TRIAL 3

DISTRIBUTION:

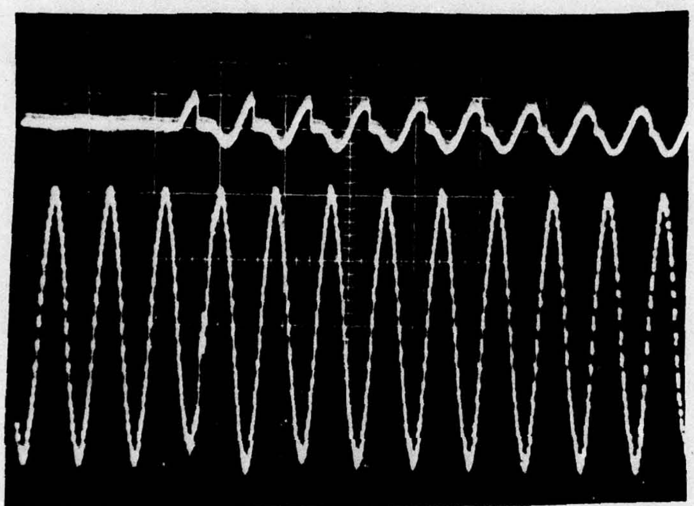
DE-255 REV. 12-66

| DELCO ELECTRONICS GENERAL MOTORS CORPORATION | REPORT NO. ITEM NO. 0005 | PAGE 21 | JOB NO. DESIGN DATA | PAGE 145 |
|---|---|---|---|---|
| TITLE | | PREPARED CORRY | | DATE 5/6/7 |
| | | CHECKED | | |
| | | APPROVED | | |

60 HZ, THREE PHASE TRANSIENT TESTS

LOAD TRANSIENTS

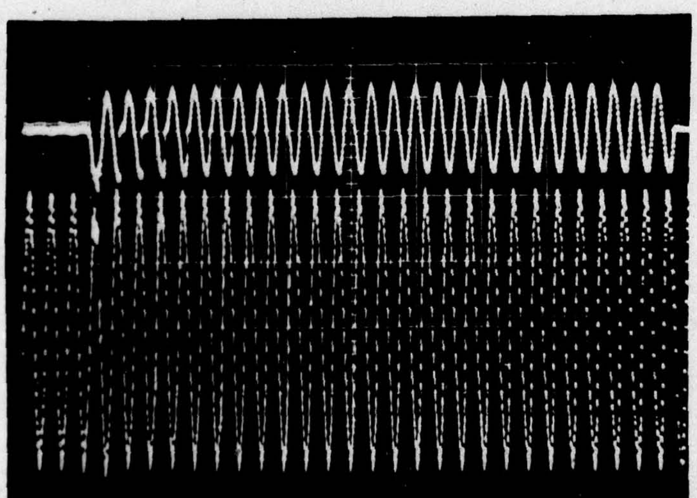
NO LOAD TO 13.2 KW
0.8PF LOAD



LOAD CURRENT
↕ 100A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE $V_o$
↔ 20 MS/DIV.

TRIAL 1

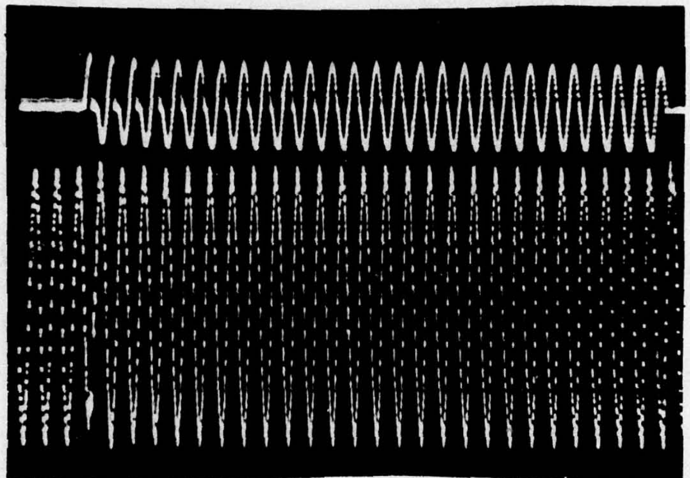


TRIAL 2

↔ 50MS/DIV.

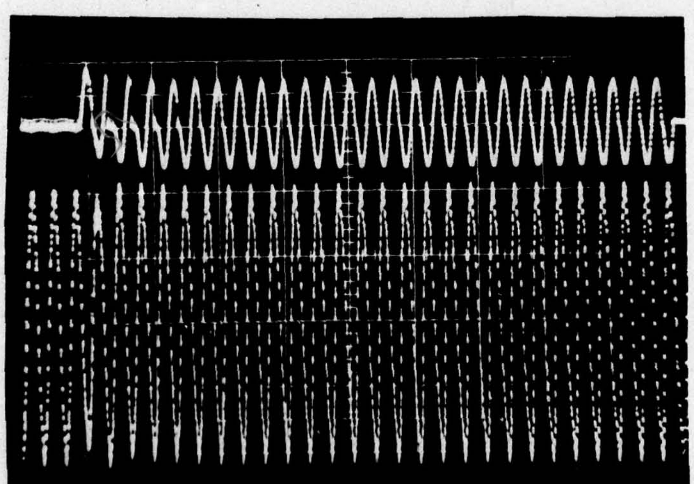
| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO.<br>ITEM NO.<br>0005 | PAGE<br>22 | JOB NO.<br>DESIGN DATA | PAGE<br>146 |
|---|---|---|---|---|

| TITLE | PREPARED CORRY DATE 5/6/74<br>CHECKED<br>APPROVED |
|---|---|



TRIAL 3

50 ms /DIV.



TRIAL 4

DISTRIBUTION:

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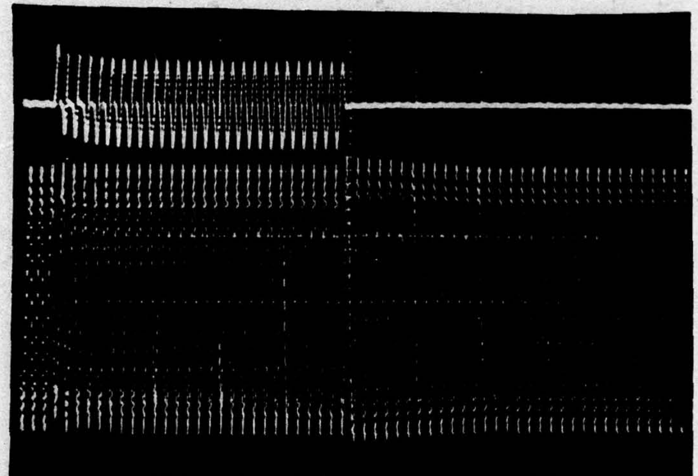
|---|---|---|---|---|
| TITLE | | PREPARED<br>CORRY | | DATE<br>5/6/7 |
| | | CHECKED | | |
| | | APPROVED | | |

# 60HZ, THREE PHASE TRANSIENT TESTS

## LOAD TRANSIENTS

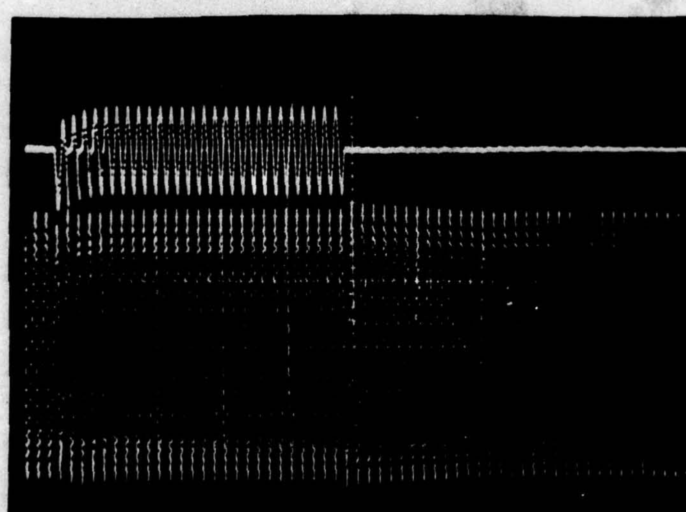
13.2KW, 0.8PF LOAD TO NO LOAD



LOAD CURRENT
↕ 100A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE $V_o$
⟷ 50MS/DIV.

TRIAL 1

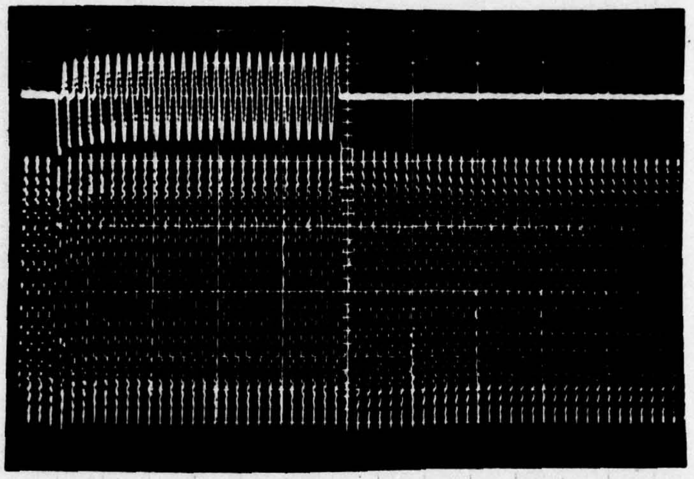


TRIAL 2

DISTRIBUTION:

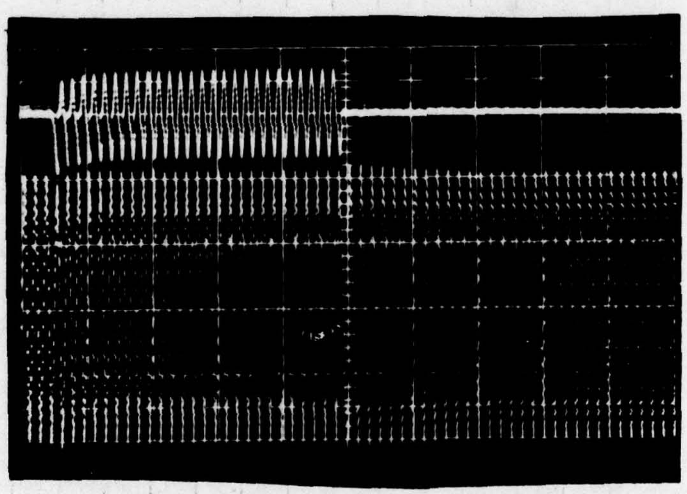
| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO.<br>ITEM NO.<br>0005 | PAGE<br>24 | JOB NO.<br>DESIGN DATA | PAGE<br>148 |
|---|---|---|---|---|

| TITLE | PREPARED CORRY | DATE 5/6/74 |
|---|---|---|
| | CHECKED | |
| | APPROVED | |

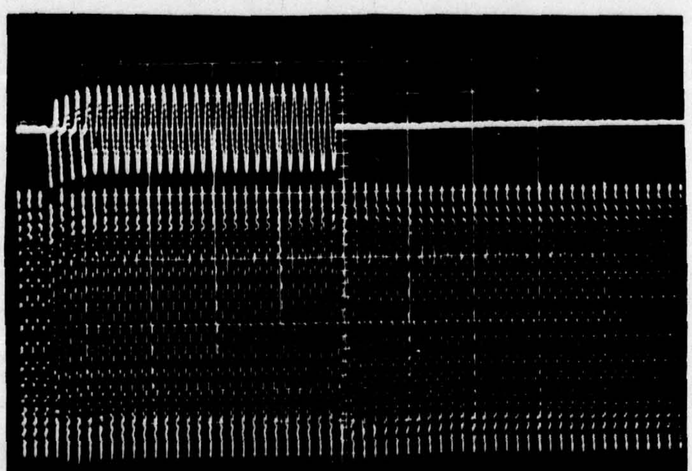


TRIAL 3

↔ 50 ms/DIV



TRIAL 4



TRIAL 5

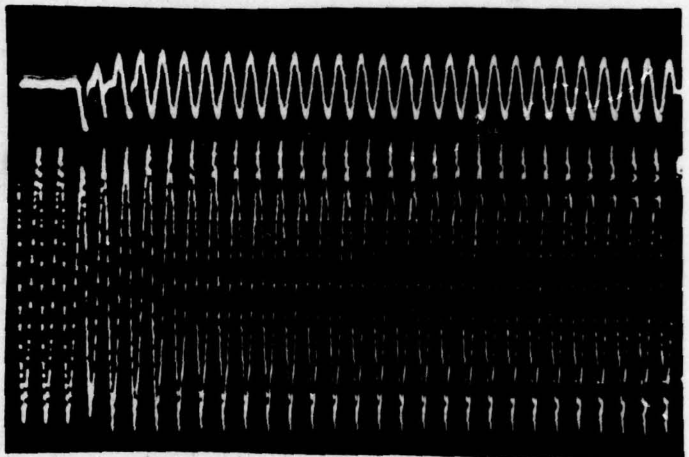
DISTRIBUTION:

| DELCO ELECTRONICS<br>GENERAL MOTORS CORPORATION | REPORT NO. ITEM NO. 0005 | PAGE 25 | JOB NO. DESIGN DATA | PAGE 149 |
|---|---|---|---|---|
| TITLE | | PREPARED CORRY | | DATE 5/6/74 |
| | | CHECKED | | |
| | | APPROVED | | |

# 60HZ, THREE PHASE TRANSIENT TESTS

## LOAD TRANSIENTS

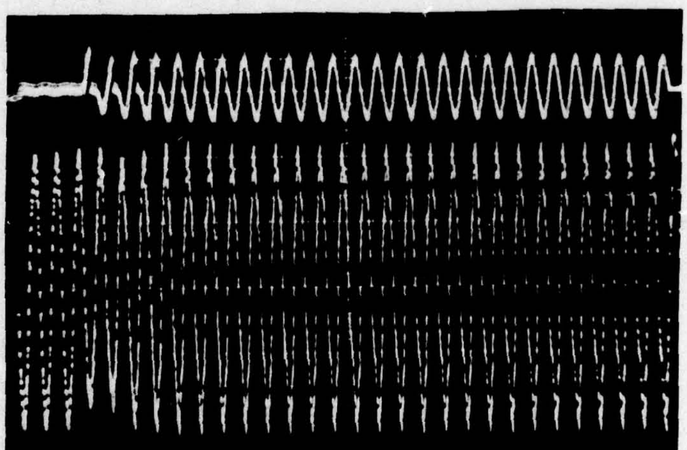
NO LOAD TO TWO P.U., 0.4 PF.



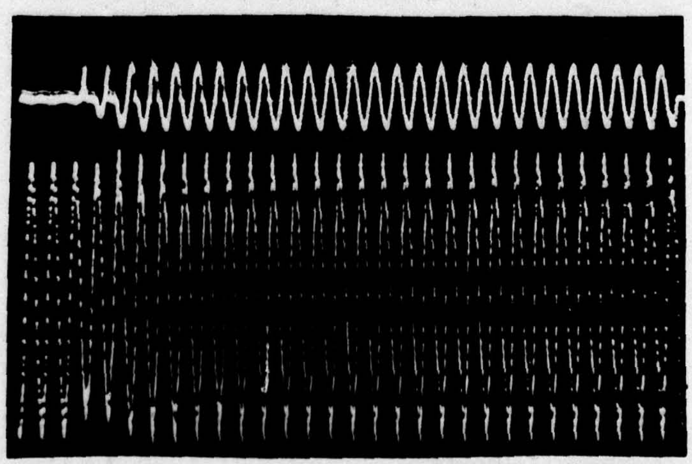
LOAD CURRENT
↕ 200A/DIV.

LINE-TO-NEUTRAL OUTPUT VOLTAGE $V_o$
↔ 20MS/DIV.

TRIAL 1



TRIAL 2



TRIAL 3

DISTRIBUTION:

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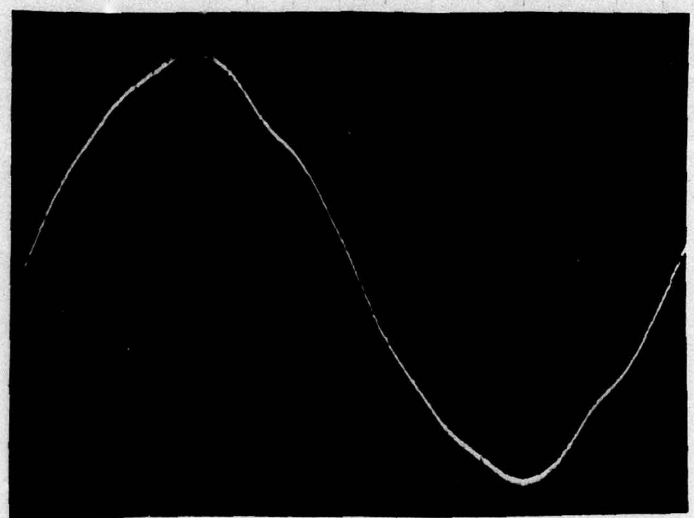
|---|---|---|---|---|
| TITLE | | PREPARED CORRY | | DATE 5/8/74 |
| | | CHECKED | | |
| | | APPROVED | | |

## 400 HZ, SINGLE PHASE, TWO WIRE LOAD TESTS

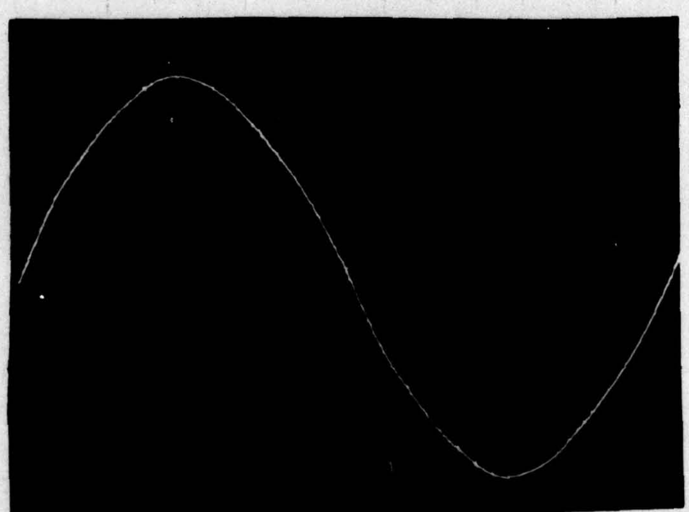
OUTPUT VOLTAGE $V_o$



NO LOAD

120.02 Vrms *

THD = 3.4%



8.8KW, 0.8PF
11KVA LOAD

120 Vrms *

THD = 2.65%

(REGULATION LOOP OPEN - MANUAL CONTROL)

DISTRIBUTION:

DELCO ELECTRONICS
GENERAL MOTORS CORPORATION

REPORT NO. ITEM NO. 0005 | PAGE 27 | JOB NO. DESIGN DATA

TITLE

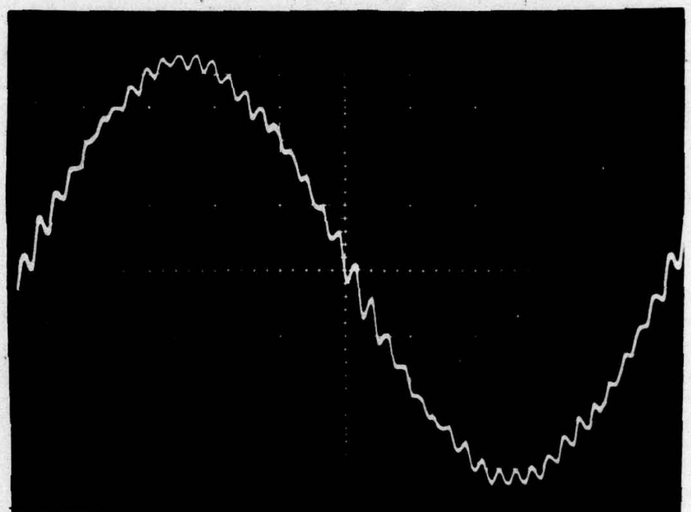
PREPARED CORRY 5/8/7

CHECKED

APPROVED

60HZ, SINGLE PHASE, TWO WIRE LOAD TESTS

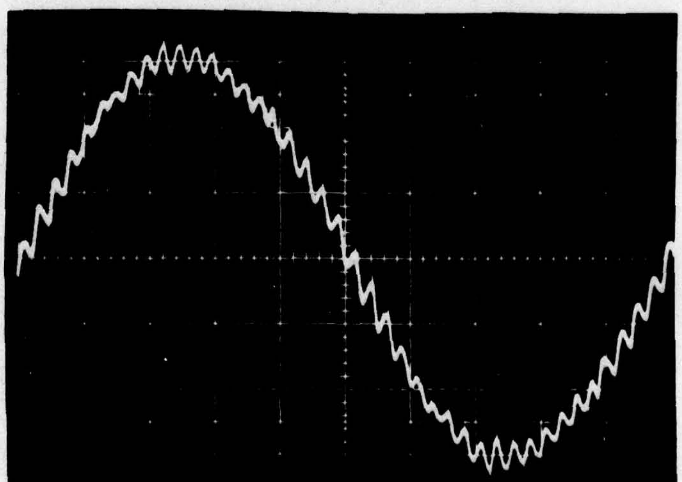
OUTPUT VOLTAGE Vo



NO LOAD

120 Vrms*

THD= 4.7%



8.8KW, 0.8 PF
11KVA LOAD

120Vrms*

THD= 5.6%

(REGULATION LOOP OPEN - MANUAL CONTROL)

DISTRIBUTION:

DF 255 REV. 12-66

10 KW FREQUENCY CONVERTER

PARTS LISTS

CDRL ITEM A002

Contract No. DAAK02-72-C-0210

**MATERIAL** MEMORY TIMING CIRCUIT

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | OSCILLATOR CTS-KNIGHT B3-0032-5 | 1 | |
| 2 | SN7490N | 2 | |
| 3 | SN74161N | 2 | |
| 4 | SN5402N | 3 | |
| 5 | MEMORY HARRISON HPROM-1-1024 | 8 | |
| 6 | CIRCUIT BOARD | 1 | |
| 7 | SWITCH SINGLE POLE, DOUBLE THROW | 1 | |
| 8 | RESISTOR 560 OHM, ½ WATT | 4 | |
| 9 | CAPACITOR 0.1MFD | 1 | |
| 10 | CAPACITOR 0.01MFD | 1 | |
| 11 | CAPACITOR 100 MFD, 10VDC | 1 | |
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| | TOTAL | | |

MATERIAL *R.F. DRIVERS*

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | CIRCUIT BOARD RSK 20296-501 | 6 | |
| 2 | SN5402N QUAD NOR GATE | 18 | |
| 3 | SN5413N DUAL NAND SCHMITT TRIGGER | 6 | |
| 4 | MHQ4002A QUAD CORE DRIVER TRANSISTORS | 18 | |
| 5 | F625-97-06 CORE, INDIANA GENERAL | 36 | |
| 6 | 2N5333 TRANSISTOR PNP | 12 | |
| 7 | RESISTOR, 5 OHM ±3% 5W. DALE NH-5 | 12 | |
| 8 | RESISTOR, 39 OHM ±5% 1W. | 12 | |
| 9 | ZENER DIODE, UZ740 40VOLT | 6 | |
| 10 | CAPACITOR, MYLAR 0.015 MFD 100VDC | 6 | |
| 11 | CAPACITOR, TANTALUM, 100 MFD 10VDC | 6 | |
| 12 | DIODE, 1N4448 | 72 | |
| 13 | HEAT SINK TX 0506-B IERC | 12 | |
| 14 | CONNECTOR, ELCO P/N 00-6007-044-980-002 | 6 | |
| 15 | T-STRUT VECTOR TS169N | 6 | |
| 16 | RETAINER KIT, VECTOR BR 19H | 4 | |
| 17 | CASE GUIDE VECTOR BR 19-6-1 3.5" | 5 | |
| | | | |
| | | | |
| | | | |
| | TOTAL | | |

**MATERIAL** TRANSISTOR RF DRIVE ISOLATION CIRCUIT
(4 REQUIRED)

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | DIODE, SEMTECH 3L05 | 2 | |
| 2 | TRANSFORMER, DELCO XT-72029 | 1 | |
| 3 | CIRCUIT BOARD | 1 | |
| 4 | TERMINAL, USECO 12A1C | 4 | |
| | | | |
| | TOTAL | | |

**MATERIAL** THYRISTOR R.F. DRIVE ISOLATION CIRCUIT

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| | SINGLE SCR DRIVE (10 REQUIRED) | | |
| 1 | DIODE 1N4448 | 4 | |
| 2 | TRANSFORMER, DELCO XT-71036 | 1 | |
| 3 | CIRCUIT BOARD | 1 | |
| 4 | TERMINAL, USECO 1281C | 4 | |
| | | | |
| | PARALLEL SCR DRIVE (18 REQUIRED) | | |
| 1 | DIODE 1N4448 | 8 | |
| 2 | TRANSFORMER, DELCO XT-72023 | 2 | |
| 3 | CIRCUIT BOARD | 1 | |
| 4 | TERMINAL USECO 1281C | 6 | |
| | TOTAL | | |

**MATERIAL** AUXILIARY POWER SUPPLY

| ITEM | PART NUMBER AND DESCRIPTION<br>**DESCRIBE IN DETAIL**<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | ARNOLD MAGNETICS CORP.<br>POWER SUPPLY ASN-M18/3-A5/2-A2.7/0.3CA | 1 | |
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| | TOTAL | | |

**MATERIAL** PROTECTION & CONTROL

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | INPUT CURRENT TRANSFORMER XT 72038 | 3 | |
| 2 | TRANSISTOR CURRENT TRANSFORMER XT 72038 | 2 | |
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| | TOTAL | | |

**MATERIAL-** MERDC 10 KW ALT. FIELD CONTROL

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | DIODE - ZENER 1N748 | 1 | |
| 2 | - " UZ760 | 1 | |
| 3 | 1N3913 | 1 | |
| 4 | 1N4448 | 9 | |
| 5 | 1N4946 | 4 | |
| 6 | 1N5418 | 1 | |
| 7 | TRANSISTOR 2N2219 | 2 | |
| 8 | " 2N3421 | 1 | |
| 9 | POWER DARLINGTON DTS-4065 DELCO | 1 | |
| 10 | INTEGRATED CIRCUIT SN7414N | 1 | |
| 11 | " " SN7402N | 1 | |
| 12 | VOLTAGE REGULATOR LM309K NS | 1 | |
| 13 | TIMMER NE555V SIGNETICS | 2 | |
| 14 | VOLTAGE COMPARATOR LM211H NS | 2 | |
| 15 | TRIMPOT - BOURNS MODEL 3250P-1-202 (2.0K) | 1 | |
| 16 | POT. 250-Ω ½W IRC RV6LAYSA251A | 1 | |
| 17 | POT. 5.0K ½W IRC RV6LAYSA502A | 1 | |
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| | | | |
| | | | |
| | TOTAL | | |

**MATERIAL**: MERDC 10KW ALTERNATOR FIELD CONTROL

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 18 | Resistor 1/4 Watt ±5% 100Ω | 1 | |
| 19 | 240Ω | 2 | |
| 20 | 330Ω | 2 | |
| 21 | 360Ω | 1 | |
| 22 | 680Ω | 1 | |
| 23 | 750Ω | 1 | |
| 24 | 820Ω | 2 | |
| 25 | 1KΩ | 1 | |
| 26 | 2KΩ | 1 | |
| 27 | 10KΩ | 1 | |
| 28 | 12KΩ | 3 | |
| 29 | 20KΩ | 1 | |
| 30 | 24KΩ | 2 | |
| 31 | 47KΩ | 2 | |
| 32 | 120KΩ | 1 | |
| 33 | 180KΩ | 1 | |
| | | | |
| | | | |
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| | | | |
| | TOTAL | | |

**MATERIAL** - MERDC 10KW ALT. FIELD CONTROL

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 34 | Resistor ½ Watt ±5% 7.5K-Ω | 1 | |
| 35 | Resistor 1 Watt ±5% 2.0K-Ω | 1 | |
| 36 | Resistor 1 Watt ±5% 3.9K-Ω | 2 | |
| 37 | Resistor 1 Watt ±5% 56K-Ω | 4 | |
| 38 | Resistor ¼ Watt ±1% 536-Ω | 1 | |
| 39 | 3.01K-Ω | 2 | |
| 40 | 3.32K-Ω | 1 | |
| 41 | 5.90K-Ω | 1 | |
| 42 | 6.04K-Ω | 1 | |
| 43 | Resistor 5 Watt ±3% DALE NH-5 200Ω | 1 | |
| 44 | (Resistor 25 Watt ±3% DALE NH-25 50-Ω) | 1 | |
| 45 | Capacitor .01 μf CERAMIC | 3 | |
| 46 | Capacitor - Mylar .047 μf | 1 | |
| 47 | .22 μf | 1 | |
| 48 | .33 μf | 1 | |
| 49 | 1.0 μf | 3 | |
| 50 | Capacitor - Tantalum 10 μf @ 35 VDC | 1 | |
| 51 | - 100 μf @ 10 VDC | 2 | |
| 52 | - 330 μf @ 6 VDC | 4 | |
| | TOTAL | | |

**MATERIAL** - MERDC 10KW ALT. FIELD CONTROL

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 53 | SWITCH 3PDT "FREQ CHANGE" 50V 1A | 1 | |
| 54 | SWITCH 2PST "FIELD CONTROL" 50V 10A | 1 | |
| 55 | LAMP 28Volt 40ma DIALCO | 4 | |
| 56 | SOCKET- LAMP DIALCO 508-7538-504 | 4 | |
| 57 | CIRCUIT BOARD CIRCO C-100-100 | 1 | |
| 58 | CONNECTOR - 44 PIN "ELCO 00-6007-044-980-003" | 1 | |
| 59 | HEAT SINK IREC TXO-0506-1B | 1 | |
| 60 | HEAT SINK - DUAL QUAD FINS $2\frac{5}{8}$" X $4\frac{1}{2}$" X $5\frac{1}{2}$" | 1 | |
| 61 | CHASSIS BOX 3" X 5" X 7" | 1 | |
| 62 | TERMINAL STRIP 6 # 10 LUGS | 1 | |
| 63UP | MISC. HARDWARE | SOME | |
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| | TOTAL | | |

# MATERIAL POWER SWITCH ASSEMBLY

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | INTERNATIONAL RECTIFIER 82-2022<br>THYRISTOR NATIONAL NL-E156E-HS15 | 22 | SCR1 THRU SCR22 |
| 2 | DIODE INTERNATIONAL REC. P/N 82-0060 | 5 | $D_1$ THRU $D_5$ |
| 3 | TRANSISTOR WESTINGHOUSE 1741-1460 | 4 | $Q_1$ THRU $Q_4$ |
| 4 | TRANSISTOR WESTINGHOUSE 1756-1460 | 4 | $Q_5$ THRU $Q_{10}$ |
| 5 | ZENER DIODE DELCO DPZ30-40R | 4 | $D_1$ THRU $D_4$ |
| 6 | RESISTOR 0.1 OHM 25W ±2% DALE NH-25 | 4 | |
| 7 | RESISTOR 10 OHM 5W ±2% DALE NH-5 | 4 | |
| 8 | CAPACITOR 0.1MFD WEST CAP 9RD16104-D | 10 | |
| 9 | RESISTOR 20 OHM 25W ±1% DALE NH-25 | 10 | |
| 10 | CAPACITOR 20MFD CORNELL-DUBILIER SCRE-105 | 1 | |
| 11 | CAPACITOR 20MFD SPRAGUE 333P12 | 3 | |
| 12 | CAPACITOR 125MFD G.E. 28F1104FC | 2 | |
| 13 | CAPACITOR 50MFD CORNELL-DUBILIER SCR2050 | 2 | |
| 14 | CAPACITOR 1.0MFD SPRAGUE 330P31 | 4 | |
| 15 | DIODE SEMTECH SCDAR4F | 1 | |
| 16 | DIODE SEMTECH SCBA4F | 2 | |
| 17 | RESISTOR 1.0 OHM 25W ±3% DALE NH-25 | 6 | |
| 18 | XT72035-01<br>TRANSFORMER 180-1200HZ STEP AUTOTRANSFORMER | 1 | $T_1$ |
| 19 | XT72034-01<br>TRANSFORMER 60-400HZ [illegible] | 1 | $T_2$ |
| 20 | XT73001<br>TRANSFORMER P.C. COMMUTATION BOOST | 1 | $T_3$ |
| | TOTAL | | |

**MATERIAL** POWER SWITCH ASSEMBLY

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 21 | XT72040<br>TRANSFORMER T4, T- COMMUTATION BOOST | 1 | T4 |
| 22 | INDUCTOR 7 MICROHENRIES | 2 | L1, L2 |
| 23 | INDUCTOR 7 MICROHENRIES | 2 | L3, L4 |
| 24 | INDUCTOR 5 MICROHENRIES | 1 | L5 |
| 25 | INDUCTOR 5 MICROHENRIES | 1 | L6 |
| 26 | INDUCTOR 7 MICROHENRIES | 3 | L7, L8, L9 |
| 27 | INDUCTOR TRIPLEN FILTER XL72022-01 | 1 | L10 |
| 28 | HEINEMANN P3XAM1516.<br>CIRCUIT BREAKER 65 AMP. | 1 | |
| 29 | RESISTOR 250 OHM 3% 25W. DALE NH-25 | 2 | |
| 30 | TYPE E<br>WIRE #12 TEFLON FLEXIBLE MIL-W-16878D | 100 FT | |
| 31 | TYPE E<br>WIRE #14 TEFLON FLEXIBLE MIL-W-16878D | 50 FT. | |
| 32 | FAN ROTRON MARK 4 GRILL SERIES 797 | 4 | |
| 33 | RECTIFIER SEMTECH SC3AS6F | 1 | |
| 34 | DIODE SEMTECH SCDAR4F | 1 | |
| 35 | ALTERNATOR OUTPUT INDUCTOR XL72026 | 1 | |
| 36 | TERMINAL SEASTROM 5903-4-16 | 2 | |
| 37 | TERMINAL SEASTROM 5903-6-8 | 1 | |
| 38 | TERMINAL AMP CAT. NO. 320574 | 500 | |
| | | | |
| | | | |
| | TOTAL | | |

**MATERIAL** *MERDC - TRANSISTOR PROTECTION CIRCUIT*

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | VOLTAGE COMPARATOR LM311D NS | 4 | |
| 2 | INTEGRATED CIRCUIT SN7400N | 2 | |
| 3 | SN7404N | 1 | |
| 4 | SN74132N | 1 | |
| 5 | SN74279N | 1 | |
| 6 | DIODE 1N4448 | 16 | |
| 7 | DIODE SBR1F | 2 | |
| 8 | Resistor 1/4 Watt ±5% 360Ω | 4 | |
| 9 | 470Ω | 4 | |
| 10 | 1KΩ | 4 | |
| 11 | 1.8KΩ | 4 | |
| 12 | 2.2KΩ | 4 | |
| 13 | 8.2KΩ | 4 | |
| 14 | 10.0KΩ | 1 | |
| 15 | Resistor 1/2 Watt ±5% 200Ω | 2 | |
| 16 | TRIMPOT- BOURNS 3250P-1-103 (10KΩ) | 1 | |
| 17 | TRANSFORMER XT72038 | 2 | |
| 18 | CAPACITOR- SILVER MICA 1000Pf | 4 | |
| 19 | CAPACITOR- CERAMIC .01μf 100VDC | 5 | |
| 20 | CAPACITOR - TANTALUM 6.8μf @ 35VDC | 1 | |
| | TOTAL | | |

**MATERIAL** MERDC - TRANSISTOR PROTECTION CIRCUIT

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 21 | CIRCUIT BOARD CIRCO C-100-100 | 1 | |
| 22 | CONNECTOR ELCO P/N 00-6007-044-980-003 | 1 | |
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| | TOTAL | | |

POWER SWITCH ASSEMBLY

MATERIAL CONTRACT NO. DAAK02-72-C-0210
MODIFICATION P0003 (SINGLE PHASE INVESTIGATION)

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 1 | THYRISTOR INTERNATIONAL RECTIFIER 82-2022 OR NATIONAL NL-F156C-HS15 | 22 | |
| 2 | DIODE INTERNATIONAL RECTIFIER 82-0060 | 2 | |
| 3 | TRANSISTOR WESTINGHOUSE 1781-1460 | 4 | |
| 4 | TRANSISTOR WESTINGHOUSE 1752-1460 | 4 | |
| 5 | ZENER DIODE DELCO DPZ30-50B | 4 | |
| 6 | RESISTOR 0.1 OHM ±3% 25W. DALE NH-25 | 4 | |
| 7 | RESISTOR 10 OHM ±3% 5W DALE NH-5 | 4 | |
| 8 | CAPACITOR 0.1MFD WEST CAP 980161040 | 10 | |
| 9 | RESISTOR 20 OHM ±1% 25W DALE NH-25 | 10 | |
| 10 | CAPACITOR 20MFD CORNELL-DUBILIER SCR26405 | 1 | |
| 11 | CAPACITOR 60MFD SPRAGUE 233P13 | 3 | |
| 12 | CAPACITOR 125MFD G.E. 28F1104FC | 2 | |
| 13 | CAPACITOR 1.0MFD SPRAGUE 220P21 | 4 | |
| 14 | CAPACITOR 20MFD SPRAGUE 233P12 | 1 | |
| 15 | CAPACITOR 50MFD CORNELL-DUBILIER SCR2020 | 2 | |
| 16 | RECTIFIER SEMTECH SC3M5GF | 1 | |
| 17 | DIODE SEMTECH SCPA4F | 2 | |
| 18 | RESISTOR 5 OHM ±3% 25W. DALE NH-25 | 2 | |
| 19 | TRANSFORMER STEP-AUTO XT73026 | 1 | |
| 20 | TRANSFORMER 60-400 HZ 216-216 XT72034-01 | 1 | |
| | TOTAL | | |

MATERIAL POWER SWITCH ASSEMBLY

DAAK02-72-C-0210 MOD. P0003

| ITEM | PART NUMBER AND DESCRIPTION<br>DESCRIBE IN DETAIL<br>PART NO., VENDOR CODE, SPECIFICATION, DIMENSION, UNIT, TRADE OR BRAND NAME, COLOR, TYPE OF MATERIAL, ETC. | QTY | |
|---|---|---|---|
| 21 | INDUCTOR 5.5 MICROHENRIES | 1 | |
| 22 | INDUCTOR 15 MICROHENRIES | 1 | |
| 23 | INDUCTOR TRIPLEN FILTER XL-73014 | 1 | |
| 24 | TRANSFORMER XT-72038 | 1 | |
| 25 | TRANSFORMER XT-72033 | 2 | |
| 26 | TRANSFORMER SINGLE PHASE OUTPUT XT-73030 | 1 | |
| 27 | CIRCUIT BREAKER HEINEMANN F-3XAM1516 | 1 | |
| 28 | FAN ROTRON MARK 4 GRILL SERIES 747 | 4 | |
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